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FACULTEIT PSYCHOLOGIE EN
PEDAGOGISCHE WETENSCHAPPEN

Conflict monitoring and reinforcement learning

Senne Braem

Promotor: Prof. Dr. Wim Notebaert

Proefschrift ingediend tot het behalen van de academische graad
van Doctor in de Psychologie

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Senne,

8 april 2013

CHAPTER 1
INTRODUCTION

As the deadline for submitting my dissertation is approaching, spring is showing its first signs. The sun is inviting me to go outside and have that much yearned-for first beer in the sun with my friends. But I can't. I shouldn't. My "cognitive control"-system is running on an all time high, helping me to stay inside and focus on those millisecond effects I've been gathering the last three and a half years. Why is it doing that? And how does this work? These were the questions I wanted to address. During my time as a PhD student, we (my helpful colleagues and I) have been collecting data to address the question on how, but also why, we adapt so quickly to ever-changing environments, and how we control all this incoming information as to avoid conflicting responses. For example, when starting our computer, our desktop presents us with a range of desktop icons to choose from. Although we're well aware that we should be opening our text-editor to finish that project we started long ago, we often find ourselves clicking on our web browser first, and before we know we're leaning back and watching funny videos of kittens on the internet. This often happens before we realize and therefore not always constitutes a conscious decision towards a more pleasing option, but rather a well-trained automatic prepotent response that, through learning, has been associated with immediate reinforcements (Skinner, 1953).

However, we do not always follow our impulses and, especially when stakes are high, we can be surprisingly efficient in ignoring what is irrelevant, and focusing on what is important. In fact, as a product of evolution, we exhibit an astonishing capacity for flexible thought and action: we can swiftly adapt and regulate our attention to environmental demands, efficiently switch back and forth between multiple tasks, and regulate our impulses appropriately. These characteristics of human (and non-human) behavior are often referred to with the umbrella term *cognitive control*.

In this project, we mainly focused on how we deal with cognitive conflict. That is, when confronted with two different options, how are we able to override automatic action tendencies (i.e. opening our web browser) as to select the more appropriate action (i.e. opening our text editor) that guarantees successful task performance (i.e. finishing our project)? Our study of cognitive control will mainly revolve around this monitoring of, and adapting to, cognitive conflict and will often be referred to with the slightly more specific term *conflict monitoring*.

Conflict monitoring can be seen as a manifestation or subprocess of "cognitive control", as has been argued by Botvinick, Braver, Barch, Carter, and Cohen (2001) in their by now classic paper called "Conflict monitoring and cognitive control". By contrast, note that this PhD project is entitled "Conflict monitoring and reinforcement learning". While it is by no means an attempt to falsify the postulations of Botvinick and colleagues (or to compare the impact of their work to ours), we did aim at specifying some of these first notions on conflict monitoring and shed a new light on this research domain by examining if, and how, conflict monitoring can be explained by, and interacts with, reinforcement learning.

Reinforcement learning is a very broad construct - almost a philosophy - dealing with concepts like reward and punishment learning, the formation of stimulus-response associations, reward prediction errors and more (for a brief introduction on reinforcement learning, see below). Therefore, the studies in this dissertation and their obtained results are by no means exhaustive, but are meant to complement and add to an expanding line of research that investigates the interactions between cognitive control and reinforcement learning. Recent neuroscientific studies (for reviews, see Jocham & Ullsperger, 2009; Montague, Hyman, & Cohen, 2004) already related cognitive control to a (dopamine) learning system, and current models, some developed at our own department (Verguts & Notebaert, 2008; 2009; Silvetti, Seurinck, & Verguts, 2011), successfully captured conflict monitoring in terms of general reinforcement learning principles.

The research presented in this dissertation is motivated by these models, aiming to unravel the interactions between reinforcement learning and conflict monitoring.

In what follows, we will describe in more detail how we typically investigate cognitive conflict and, more importantly, adaptations to cognitive conflict. Next, we will introduce reinforcement learning and why we believe the further theorizing on conflict monitoring could be improved by taking into account reinforcement learning principles. Lastly, we will outline some predictions on how we can investigate these conflict monitoring and reinforcement learning interactions and introduce our empirical studies that form the body of this dissertation.

CONFLICT: FROM THE FIELD TO THE LAB (AND BACK TO THE FIELD)

We described conflict monitoring as a cognitive control process, but what is this conflict that requires monitoring? We experience conflicts in our actions and perceptions on an everyday basis (Figure 1a). We have built-in or well-trained action tendencies that often interfere with planned behavior or information processing. In the laboratory, the prime research tool for studying such conflicts are conflict tasks, where irrelevant information can interfere with or facilitate task performance. A great deal of conflict tasks have been developed over the last century, but we will restrict ourselves to introducing perhaps the three most well-studied conflict tasks, the Stroop task (Stroop, 1935), the Eriksen flanker task (Eriksen & Eriksen, 1974), and the Simon task (Simon, 1969), also being the three conflict paradigms that we employed during our empirical studies.

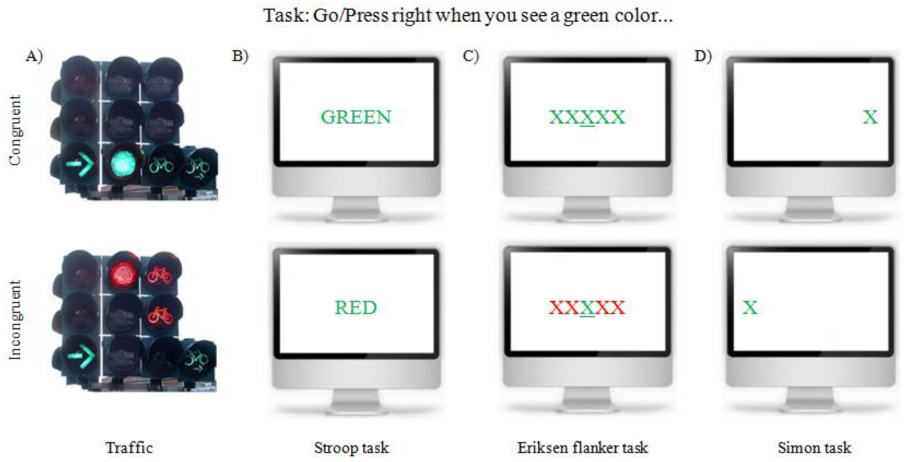

Figure 1. Examples of conflict situations and tasks. A. An everyday conflict situation in traffic where, in the incongruent situation, you would be eager to slow down at first, but, on closer inspection, notice that you are allowed to make a right turn after all. B. In the Stroop task, participants are distracted by the word meaning that could either facilitate (congruent) or interfere (incongruent) with responding to the color of the word. C. In the Eriksen flanker task, performance is facilitated or impeded by presenting similar (congruent) or interfering (incongruent) irrelevant stimulus information next to the centrally presented target. D. In the Simon task, the conflict is determined by the spatially irrelevant location of the stimulus. When the task is to press right when a green stimulus appears on the computer screen, performance will be faster (slower) when the stimulus is also presented at the right (left) hand side.

One of the oldest, most well-known, and robust conflict effects is probably the Stroop effect (Stroop, 1935; MacLeod, 1991, Figure 1b). In the Stroop task, subjects are requested to name the font color of different color-words printed in different font colors. During this task, subjects are typically influenced by the word meaning despite its irrelevance to the task. Reaction times and error rates are increased when the font color and the word meaning mismatch (incongruent; e.g., ‘YELLOW’ printed in blue), as opposed to match (congruent; e.g., ‘YELLOW’ printed in yellow).

In the Flanker task (Eriksen & Eriksen, 1974; Figure 1c), participants are required to respond as fast as possible to a centrally presented target, such as identifying a certain letter (e.g., press left when 'S', right when 'H'). Irrelevant flankers presented next to the central target can impede task performance when they are incongruent, as when these letters are associated with an alternative response (e.g., 'HHSHH'), but facilitate task performance when congruent, as when they are the same letters as the central target (e.g., 'SSSSS').

Lastly, the Simon task (Simon, 1969; Lu & Proctor, 1995; Figure 1d), again a famous and extensively studied congruency task, has even been referred to as a cultural icon in experimental psychology (Proctor, 2011). It's a well-studied observation that people tend to prefer reacting to a laterally presented stimulus with the same, rather than the opposing, side of the body (Fitts & Seeger, 1953; Fitts & Deininger, 1954). However, Simon and Rudell (1967) first observed that this effect also takes place when the stimulus location is actually irrelevant to the task at hand. For example, when the instruction is to press right when the stimulus is green and left when red, participants respond faster and more accurate when the green stimulus is presented on the right side (or the red left), than when it is presented on the left side of the screen (or the red right). This congruency effect is referred to as the Simon effect (Simon, 1969).

Over the last decennia these congruency tasks have been of exponentially increasing interest to cognitive psychologists and beyond, and led to the development of important models of cognitive control (see below). Conflict effects have been widely studied in computer tasks to investigate human, but also animal (Courtière, Hardouin, Burle, Vidal, & Hasbroucq, 2007; Urcuioli, Vu, & Proctor, 2005), behavior. In fact, even when tested outside isolated lab environments, reliable influences of irrelevant information on more complex motor behavior (i.e. the Simon effect) have been observed. For example, when we confronted experienced basketball players with the task to shoot a ball at one of the two basketball goals placed right in front of them, dependent on the pitch of a tone in their wireless headphone, they were better at shooting at the rightmost (leftmost) goal when the appropriate sound was presented in their right (left) ear, than when it was presented in their left (right) ear, $\chi^2 = 4.229$, $p < .05$. Similarly, when requesting experienced bowlers (affiliated with the national bowling team) to throw over the rightmost or leftmost pin depending on the pitch of a tone, they threw more accurately when the location of the sound was congruent with the location of their aimed-for pin, $\chi^2 = 5.108$, $p < .05$, despite the fact that the location of this sound was irrelevant to the task (Braem, Supply, Roels, & Notebaert, submitted).

MONITORING AND ADAPTING TO CONFLICT

Although conflicts can slow us down, or even lead us into making mistakes, we are often able to learn from, or adapt to, these conflicting situations. For example, one of the most prominent cognitive control effects is the observation that the influence of irrelevant stimulus information is reduced after a trial where conflict occurred. This was first observed in a flanker task by Gratton, Coles and Donchin (1992; Figure 3b), who reported a reduced congruency effect (i.e. the difference score after subtracting the reaction times of a congruent trial from the reaction times of an incongruent trial) after incongruent than after congruent trials. This effect is often referred to as the "conflict adaptation effect", "congruency sequence effect", or Gratton effect, after the first author of the original paper. We will use these terms interchangeably throughout this dissertation, as it will be our index of cognitive control in our first four empirical chapters. Soon after its first observation, the Gratton effect sparked a great deal of interest, and has been reproduced in other congruency tasks like the Simon task (Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002) and the Stroop task (Kerns et al., 2004).

In their influential conflict monitoring theory, Botvinick and colleagues (2001) offered a first explanation for the Gratton effect in terms of a top-down modulation of attention processes. Specifically, they proposed there to be a constant monitoring of conflict in information processing that computes a quantifiable measure of conflict, which can be used to trigger an adaptive mechanism that enhances task-specific processes. By assuming that something continuously monitors a level of conflict, a role attributed to the anterior cingulate cortex (ACC), the conflict monitoring account was "the first" to propose a measure as to when cognitive control has to intervene.

Although this was, and still is, a significant step forward in the development of theories on cognitive control, the conflict monitoring account, despite being specific about the monitoring process, is rather vague about the subsequent adaptation processes, or how cognitive control is implemented. The conflict monitoring account suggested that there is a "conflict monitoring loop", connecting conflict monitoring to a "cognitive control system", ensuring that task-relevant bottom-up processes would be enhanced after conflict detection. For example, in a flanker task, conflict would then increase the processing of targets and decrease the processing of flankers; while in a Stroop task, the detection of conflict would enhance color processing and reduce word processing. Even though this sounds like an interesting approach, the conflict monitoring model does not specify how it knows which task it should pay more attention to. Although it implements control in a task-specific way, there is no system installed that directs attention more to one task than the other. This is problematic, especially given that adaptations to conflict indeed occur in a task-specific manner (Kiesel, Kunde, & Hoffman, 2006; Notebaert & Verguts, 2008). In fact, conflict control is even believed to be working in an item- and context-specific way (Abrahamse, Duthoo, Notebaert, & Risko, in press; Bugg, Jacoby, & Chanani, 2011; Cañadas, Rodríguez-Bailón, Milliken, & Lupiáñez, in press; Crump, Gong, & Milliken, 2006; Crump, Vaquero, & Milliken, 2008; Crump & Milliken, 2009; Heinemann, Kunde, & Kiesel, 2009; Jacoby, Lindsay, & Hessels, 2003; King, Donkin, Korb, & Egner, 2012a; King, Korb, & Egner, 2012b; Leboe & Mondor, 2007). Because of its architecture, the conflict-monitoring model cannot account for these observations, akin to the idea that conflict control might rely on more associative forms of cognitive control than first thought.

Secondly, although the original conflict monitoring theory (Botvinick et al., 2001) offered interesting insights as to when, and how (but see previous paragraph), cognitive control can be exerted, it remains unclear as to why cognitive control should be exerted (but see Botvinick, 2007). To some, this may seem as a trivial matter at first, but we believe it is important to investigate, especially from a reinforcement learning perspective, the drive (i.e. motivational factors) behind cognitive control, as this may further help us understanding its dynamics. Therefore, we argue that interactions with, and notions of, reinforcement learning can be a helpful tool to better understand how we deal with conflict. Hereafter, we will provide a brief overview of reinforcement learning, both as a concept and as a research domain, to then return to the matter of conflict monitoring and adaptation, and see how some of these concepts can help us in investigating the underlying nature of these intriguing mechanisms that define our everyday action, perception, and decision making.

REINFORCEMENT LEARNING

Reinforcement learning theory dates back to the beginning of the last century. Ivan Pavlov (1928, Figure 2) first introduced the term reinforcement to describe the strengthening of associations between a conditioned (e.g. a bell) and an unconditioned stimulus (e.g. food) resulting from their simultaneous presentation. However, although the focus of Pavlov's work, and his use of the term reinforcement, was mostly restricted to stimulus-stimulus associations, the definition was soon extended to response learning as well. Thorndike's famous Law of Effect (1911) can be seen as a first manifestation of this idea, stating that responses in a certain situation that are closely followed by satisfactory stimuli, will be more likely to re-occur, when this situation represents itself again. These traditional models of reinforcement learning only focused on the formation of associations, without focusing on the underlying internal states. In fact, behaviorists, being the first proponents of reinforcement learning, were strongly opposed to ascribing measurable behavior to internal intervening states (Skinner, 1963). Early studies of reinforcement learning were characterized by this school of thought and are still, up until today, often described within this (sometimes oversimplified) philosophy.

However, the concept of reinforcement learning how we will use it throughout this dissertation is not just a modern recapitulation of these stimulus-response learning mechanisms familiar from this classical and instrumental conditioning literature (see also Montague et al., 2004). Instead, reinforcement learning covers ideas from these century-old theories up to modern computational models of machine learning and neuroscience. Scientific techniques have much progressed and we now gained insight in reinforcement learning rules that often describe specific neurotransmitter functions. As stated by B. F. Skinner himself: "*The importance of behaviorism as a philosophy of science naturally declines as a scientific analysis becomes more powerful, because there is then less need to use data in the form of self-description*" (p. 957, Skinner, 1963). Although we are still far from understanding the exact working of the human brain, it are exactly those scientific advantages in computational models of how the neural system sets goals, computes values, and guides choices, that now motivate us in investigating the (neural) underpinnings of cognitive control in terms of reinforcement learning processes.

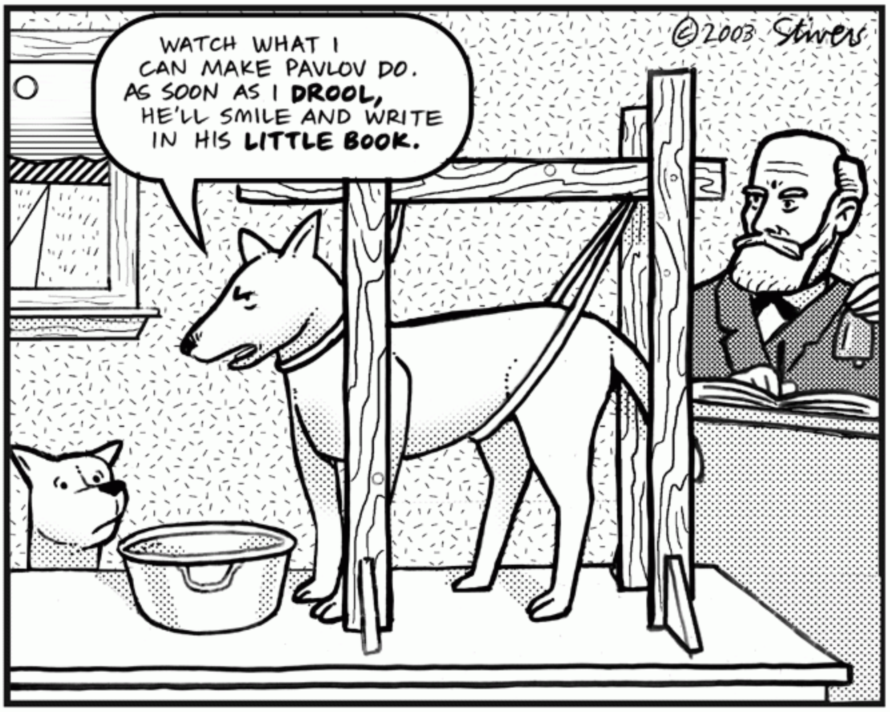

Figure 2. Popular cartoon about Pavlov's dog. The term "reinforcement" was first introduced by Pavlov (1928) to describe the formation of an association between an unconditioned and conditioned stimulus. This was demonstrated in his by now famous experiment where he presented a dog with a ringing bell (conditioned stimulus) followed by food (unconditioned stimulus). Soon, "Pavlov's dog" started drooling (unconditioned response) whenever he heard the bell. Reproduced with permission of Mark Stivers© 2003.

Reinforcement learning in general is concerned with how an animal or agent takes actions in an environment as to maximize a quantitative "reward" signal. A reinforcement learning agent learns from the outcomes of his actions, rather than being explicitly taught (i.e. by a knowledgeable teacher or reasoning from a complete model of the environment), and selects its actions on the basis of past experiences (exploitation) or new choices (exploration) (Sutton & Barto, 1998; Woergoetter & Porr, 2008). Modern reinforcement learning is highly interdisciplinary; ranging from students of machine learning and artificial intelligence to neuroscientists investigating the synaptic plasticity of neurons. The former equipped us with interesting learning rules that soon proved their applicability for explaining animal/human behavior, whereas the latter mainly contributed to the theorizing of neuromodulations and the role of reward prediction errors therein. The list of developments within this research field is endless. Therefore, we will restrict the following discussion of reinforcement learning to three concepts, important for outlining our predictions: Hebbian learning, Reward learning and reward prediction errors, and the Exploration/Exploitation trade-off.

Hebbian learning

An important question is how organisms form associations between different stimulus features, or stimulus features and action tendencies. This problem has been referred to as the binding problem (Hommel, 2004; Treisman, 1996) and one solution may lay in a learning rule put forward by Donald O. Hebb (Hebb, 1949). Largely inspired by Pavlov and others (Brown & Milner, 2003), Hebb wrote the successful book entitled "The Organization of Behavior: A Neuropsychological Theory" where he postulated that “*when an axon of cell A is near enough to excite a cell B and repeatedly and persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A’s efficiency,* *as one of the cells firing B, is increased*". This idea is often abbreviated with the more straightforward saying "*what fires together, wires together*" and represents the core message of Hebb's proposition (Hebb, 1949). Specifically, Hebb suggested that excited or "activated" neurons tend to decrease their discharge to inactive neurons, while increasing this discharge to active neurons, thereby forming an association between neurons that are simultaneously firing. Hebbian learning inspired much of our current understanding of neural connections (Seung, 2000) and has since been proven to be a largely successful tool in the computational modeling of human learning and learning failures (for a critical review, see McClelland, 2006). In fact, below we will demostrate how a simple Hebbian learning rule, as described above, might help in explaining the context- and item-specificity of cognitive control (Verguts & Notebaert, 2008; 2009).

Reward learning and reward prediction errors

Hebbian or not, learning rules, according to reinforcement learning advocates, are applied and updated as a function of certain goals. These goals or reward signals could range from direct pleasure (e.g. eating), to an indirect reward (e.g. money to buy food), or even more long-term goals (e.g. planning a vacation trip), and are widely thought to reinforce stimulus-response associations (i.e., the law of effect; Thorndike, 1911) and modulate our attention accordingly (Hickey, Chelazzi, & Theeuwes, 2010; Hickey & van Zoest, 2012; Raymond & O'Brien, 2009; Rutherford, O'Brien, & Raymond, 2010). Insights in how (task) goals and rewards modulate attention has helped in further understanding the dynamics of attention regulation. Analogously, we believe that a proper investigation of reward effects on conflict adaptation, can help us to further comprehend what drives adaptations to conflict.

In the modeling of Hebbian learning rules (Roelfsema & Van Ooyen, 2005), these goals are specified by the δ-parameter, denoting the reinforcement factor. This reinforcement factor typically represents a contrast between the current reward, or predicted reward, and an expected value. Specifically, according to a temporal difference learning algorithm, this follows a function that incorporates information about the current reward state, and the next prediction made by the reward-prediction system (Sutton & Barto, 1998; for its impact on neuroscience, see Montague et al., 2004). Important for us, although convincingly remonstrated in reward learning studies (Schultz, 2002, 2004), these reward prediction errors may also be central to how we monitor our task performance (e.g. monitor conflict), even in the absence of reward deliveries (Alexander & Brown, 2011; Silvetti et al., 2011).

Exploration and Exploitation

We exemplified how learning could occur, and how rewards and reward prediction errors might constitute important learning signals therein. However, as a last topic of interest for the current dissertation, we are also interested in knowing how a system decides when to focus, and when to start exploring (Gittins & Jones, 1974). Therefore, a central issue to reinforcement learning, is the investigation of the trade between exploration and exploitation (Kaelbling, 1993; Sutton & Barto, 1998). In order to maximize reward, a reinforcement learning agent will tend to prefer actions that were effective in producing reward (Thorndike, 1913). This calls for exploiting what already works. However, in order to select the most appropriate action, the agent first has to explore different potential options. Even when an optimal strategy has been learned, it does not hurt to keep an open mind for strategies that might work better in the future. This dilemma, between exploration and exploitation, is at the heart of reinforcement learning. In instructed, or supervised learning, this issue does not even arise (Sutton & Barto, 1998). As we will argue below, we can see the Gratton effect (enhanced task focus after conflict) as a conflict-induced form of exploitation. Although this is mostly beneficial when performing single conflict tasks, such processes can interfere with efficient task performance in task-switching studies, where a more exploratory mode is often advantageous (see below).

These notions of reinforcement learning equip us with a toolbox that can help us to further identify the processes underlying conflict monitoring and adaptations to conflict. In the following paragraphs, we will demonstrate how models of cognitive control already developed towards integrating reinforcement learning aspects into modeling cognitive control behavior, and elucidate how we can put some of the resulting predictions to the test.

CONFLICT MONITORING AND REINFORCEMENT LEARNING

Looking at the conflict monitoring literature, through the glasses of a reinforcement learning proponent, we can postulate some first assumptions. First, we would argue that adaptations to conflict constitute a purely reactive form of behavior[1], comprising a reaction to our environment that allows us to interact more efficiently with, and learn from, that environment. Second,

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[1] This does not mean that we deny the existence of more anticipatory, sustained, forms of cognitive control (Braver, 2012). Manipulations in sustained forms of control can also influence adaptations to conflict (e.g. Duthoo, Abrahamse, Braem, & Notebaert, submitted; Soutschek, Strobach, & Schubert, 2012; van Steenbergen, Band, & Hommel, 2010; Weldon, Mushlin, Kim, & Sohn, 2013) and could be implemented by modifying learning parameters or connection weights, thereby creating a more long-term impact on behavior. However, it does mean that reinforcement learning postulates that every action is taken as a reaction to its environment, and conflict adaptation in particular, as we believe, can be considered as a prime example of stimulus-driven reactive control (see also Duthoo & Notebaert, 2012; Egner, Ely, & Grinband, 2010).

conflict adaption takes place by updating and strengthening associations, rather than attributing these processes to a "cognitive control system". The latter, we believe, should be seen as a "working title", that we, and others, often use to relocate, rather than resolve, the homunculus problem (i.e. assigning unknown processes to a little agent inside our head, Hazy et al., 2007). Third, these conflict adaptation processes are part of a reinforcement learning process and, hence, in function of maximizing reward. Note that reward signals should not necessarily be seen as explicit reinforcement signals alone (i.e., money, food), but can also constitute more abstract goals that we often pursue (e.g., planning a career). In fact, when performing a simple reaction time task, "being right" could already be its own goal or reward (Satterthwaithe et al., 2012; see below). Finally, adaptations to conflict are an integral part of our constant balancing between exploration and exploitation. In everyday life we have more freedom than we have as a participant, in the sense that we can interrupt tasks and switch to tasks that have a higher expected outcome value. Within the reinforcement learning framework, task switching can be considered as exploratory behavior and conflict adaptation as exploitive behavior.

We are far from the first to consider reinforcement learning dynamics in understanding cognitive control behavior (Alexander & Brown, 2011; Hazy et al., 2007; Holroyd & Coles, 2002; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004; Silvetti, Seurinck, & Verguts, 2011; Verguts & Notebaert, 2008; 2009). Actually, this idea, and hence this dissertation, is part of an exponentially growing trend that has characterized the past decade. In what follows, we will demonstrate how we can apply the above-mentioned concepts of reinforcement learning (or how some have already been applied) for a better understanding of conflict adaptation. We will discuss the appropriate frameworks and outline our predictions that will be tested in the empirical chapters.

Conflict adaptation by Hebbian Learning

We demonstrated how the conflict monitoring account (Botvinick et al., 2001) cannot account for item- or context-specific findings of conflict control. As a reaction to this observation, Verguts and Notebaert (2008, 2009; Figure 3a) explain the Gratton effect (Figure 3b) by a conflict-modulated Hebbian learning rule (Hebb, 1949). Specifically, the authors proposed that conflict detection leads to a neuromodulatory signal that subsequently interacts with ongoing Hebbian learning and influences binding of all active representations (see also Blais, Robidoux, Risko and Besner, 2007; Davelaar & Stevens, 2009). In this view, cognitive control operates by adjusting active stimulus-response associations. Because task-relevant representations are usually more active than task-irrelevant representations, task-relevant associations will tend to be more strongly modified. This way, despite the learning rule being very general (i.e., all active associations will be enhanced), its implications are very specific. It allows us to explain why congruency effects are typically reduced for relevant stimulus features that are being presented in a higher proportion of incongruent trials (Abrahamse, Duthoo, Notebaert, & Risko, in press; Bugg, Jacoby, & Chanani, 2011; Jacoby et al., 2003; Leboe & Mondor, 2007), or for items presented on locations associated with a higher proportion of incongruent trials (Cañadas et al., in press; Crump et al., 2006; Crump, Vaquero, & Milliken, 2008; Crump & Milliken, 2009; Heinemann, Kunde, & Kiesel, 2009). However, following the Hebbian learning rule implemented in the model of Verguts and Notebaert (2008, 2009), we can even go further, and hypothesize that trial-to-trial adaptations to conflict should be specific to task-irrelevant contexts (Chapter 4) or response modalities (Chapter 2) that are not predictive of a congruency proportion.

If we extend the reasoning that task-associations are enhanced after conflict to task-switching studies, we can expect this conflict-induced strengthening of task-associations would also impact task-switching behavior. Indeed, it has been observed that the task-switch cost (the decrease in performance associated with switching between two tasks, compared to repeating the same task) is enhanced after cognitive conflict (Goschke, 2000; Brown, Reynolds, & Braver, 2007; Figure 3c). Specifically, in a task-switching design with two conflict tasks, participants show larger task-switch costs after incongruent trials than after congruent trials. This suggests that participants benefit from task repetitions but suffer from task alternations following an incongruent trial, and is consistent with the view that the detection of conflict on incongruent trials is used to increase task-relevant connections, thereby increasing the focus on task-relevant information (Verguts & Notebaert, 2008; 2009). This effect, as another metric of adaptations to conflict, will be our measure of interest in Chapter 3 and 7, and will interchangeably be referred to as the "conflict-modulated task-switch cost", the "conflict-enhanced task-switch cost", or the Goschke effect.

Interestingly, although the neural signatures of the Gratton effect have been well investigated (e.g., Egner & Hirsch, 2005), the associated brain regions with the Goschke effect have not yet been tested. Therefore, in Chapter 7, we simultaneously recorded brain imaging data by means of functional magnetic resonance imaging (fMRI), allowing us to identify the neural underpinnings of the Goschke effect. Consistent with the conflict monitoring account (Botvinick et al., 2001) and adaptation by binding account (Verguts & Notebaert), we expected this effect to be primarily associated with dorsolateral prefrontal cortex activation, consistent with an enhanced re-updating of task-associations and task goals (Niendam et al., 2012; Dosenbach et al., 2006; Duncan & Owen, 2000; Macdonald et al., 2000) on task alternations after incongruent trials. In a similar vein, Hyafil, Summerfield, and Koechlin (2009) already demonstrated how the dlPFC was most recruited on task-switches where both the current and preceding trial were incongruent.

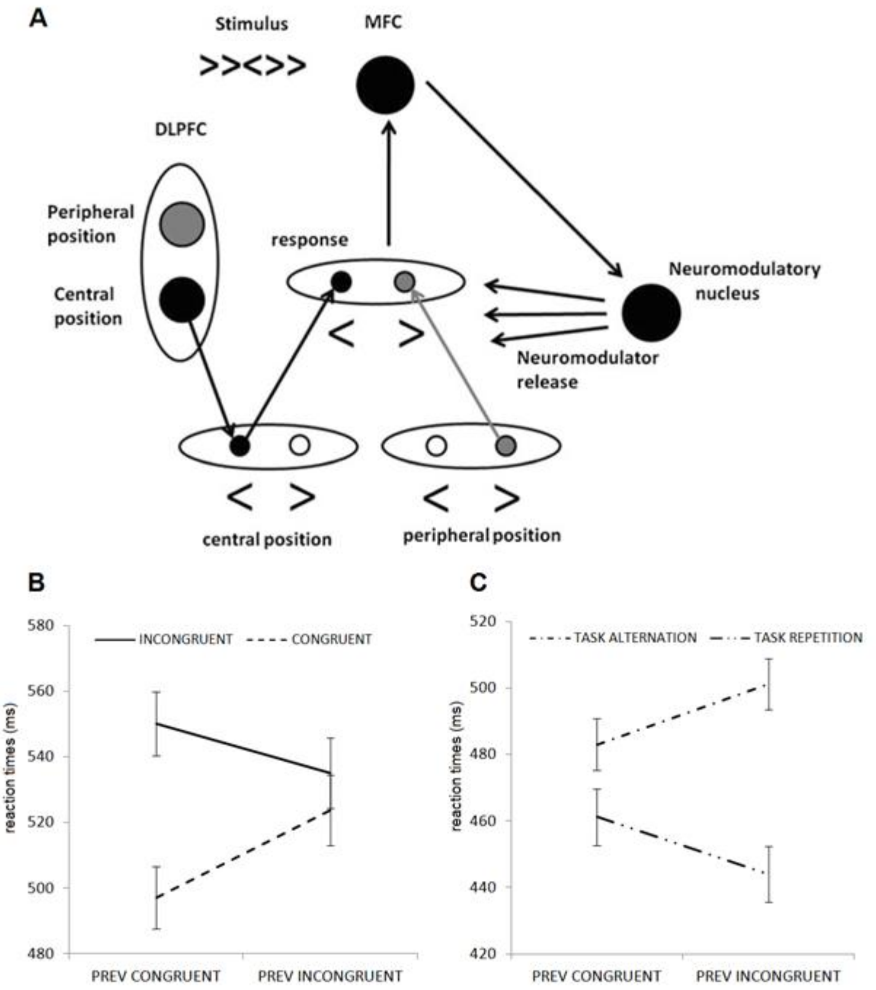

Figure 2. A. Schematic overview of the adaptation-by-binding model by Verguts and Noteabert (2008, 2009) as depicted in the article from van Bochove, Van der Haegen, Notebaert, and Verguts (2012). The overview demonstrates how conflict is detected by the Medial Frontal Cortex (MFC) sending a neuromodulatory signal throughout the brain that strengthens all active task associations. **B.** Demonstration of the Gratton effect (1992), where the impact of incongruent trials on reaction times is reduced when the preceding trial was also a incongruent trials. **C.** Demonstration of the Goschke effect (2000), where the impact of task alternations on reaction times is enhanced when the preceding trial was an incongruent trial.

Reinforcement signals and conflict adaptation

In our view, the model of Verguts & Notebaert (2008; 2009) offers a better - or at least more parsimonious - implementation of how conflict control can be exerted. Furthermore, it also suggests a measure that drives people in adapting to conflict. In their model, Verguts and Notebaert (2009) propose that the arousing value associated with the experience of conflict might be what initiates the Hebbian learning process. The authors further note that, therefore, a prediction emerging from their model would be that also "*arousal-inducing but task-irrelevant stimuli should induce a stronger focus on task-relevant stimuli (i.e. Gratton-like effect)*" (p. 255, Verguts & Notebaert, 2009). In contrast to this prediction, Botvinick (2007), following up on the conflict monitoring account (Botvinick et al., 2001), argued that adaptations to conflict might actually be driven by the negative value of cognitive conflict (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, in press; Lynn, Riddle, & Morsella, 2012; Schouppe, De Houwer, Ridderinkhof, & Notebaert, 2012), positing a valence-specific, rather than arousal-driven, hypothesis as to why we would learn or adapt our behavior after conflict. Cognitive conflict comes with a cost, in that it requires a higher amount of effort and attention. According to Botvinick (2007), it is this effortful aspect of cognitive conflict that makes it aversive (Dreisbach & Fischer, 2011; Hull, 1943; Kool, McGuire, Rosen, & Botvinick, 2010).

A better insight in the drive behind adaptations to conflict (and which aspect of the conflict-experience it elicits), can be best investigated by studying the effect of reinforcement signals. Only recently, a number of studies tried to address this issue (Krebs, Boehler, & Woldorff, 2010; Lu et al., 2013; Padmala & Pessoa, 2011; Stürmer, Nigbur, Schacht, & Sommer, 2011; van Steenbergen, Band, & Hommel, 2009; 2012), but the results remain equivocal and call for a better conceptualization and dissociation of reinforcement schedules (see also Chiew & Braver, 2011; Dreisbach & Fischer, 2012b). Specifically, while some studies investigated block-wise effects of reinforcement schedules (e.g., Locke & Braver, 2008), others have investigated cue-related effects or reinforcements (e.g., Padmala & Pessoa, 2011; Savine & Braver, 2010), randomly cueing if a trial could be potentially rewarded or not. Such an enhanced motivation typically leads to enhanced task performance, as indicated by a reduced congruency effect (Padmala & Pessoa, 2011). Yet another group of studies looked at the influence of item-specific reward on conflict processing (Krebs, Boehler, & Woldorff, 2010; Lu et al., 2013). Specifically, Krebs, Boehler, and Woldorff (2010), used a four-color Stroop task, where two colors were often rewarded for good performance, whereas the other two were never. Interestingly, Krebs and colleagues, demonstrated how reward can capture your attention, by showing facilitated conflict processing when the color of the word (relevant dimension) was rewarding, and more interference when the word meaning (irrelevant dimension) was related to rewarded colors (but see, Lu et al., 2013). Together, these studies are consistent with the notion that increasing motivation (i.e., increasing reward value) enhances task-performance, commensurate with the importance of goals as stressed by reinforcement learning theories. However, although this impact of motivation is an important one to investigate, it might differ from the impact of the reinforcement signal itself. Specifically, in the above-mentioned studies, the prospect of reward was investigated by either the context (e.g., Locke & Braver, 2008), the cue (e.g., Padmala & Pessoa, 2011), or stimulus-feature (e.g., Krebs et al., 2010). These features predicted reward before reward presentation, therefore demonstrating the effect of motivational significance, rather than the impact of reward signals themselves (for a similar reasoning, see Hickey et al., 2010). To investigate the impact of reinforcement signal presentation, we need a design where these signals are not cued and randomly distributed, therefore not predictive of potential reward or punishment in the subsequent trial. This way, we can investigate the impact of reward or punishment signals on the trial-to-trial adaptations in conflict tasks (i.e., how reinforcement signals interact with the Gratton effect).

To this end, van Steenbergen, Band, and Hommel (2009; 2012) employed a flanker task, where reward signals (associated with monetary gains), punishment signals (associated with monetary losses), and neutral signals, were not cued and randomly distributed. This allowed van Steenbergen and colleagues to investigate the impact of reinforcement signals (associated with monetary gains and losses) on adaptations to conflict. The authors observed a Gratton effect when preceded by punishment and neutral trials, but not when preceded by reward trials. This was consistent with their hypothesis that positive affect (as induced by the reward signals) would counteract the aversive learning signal cognitive conflict entails (Botvinick, 2007). However, their reward and punishment signals consisted of smiley and sad faces respectively. Moreover, although these signals immediately followed response, and were associated with monetary gain or loss, they were also completely randomly distributed, potentially following performance errors. Therefore we believe their results are of important value to the investigation of affect on cognitive control, but must be dissociated from the effects of reinforcement signals. This is in line with the work from Berridge and Robinson (2003), suggesting that the hedonic and motivational aspect of reward may have different influences on cognitive control. In contrast to the findings of van Steenbergen et al. (2009, 2012), we would expect adaptations after conflict to be enhanced after reward, but also after punishments, in line with the century-old idea that reinforcement signals help updating task-associations (Thorndike, 1911; Skinner, 1953; Schultz, 2002). To this end, reinforcement stimuli that are not confounded with affect-inducements (as administered in all above mentioned studies, except for van Steenbergen et al., 2009, 2012) should be preferred. Moreover, to make a clear dissociation between reward and no-reward trials, or punishment and no-punishment trials, the simultaneous administering of reward, punishment, and no-feedback trials within one experiment should be avoided. As indicated by van Steenbergen himself, the inclusion of all three trial types (reward, neutral, and punishment) did not allow him to make a clear dissociation, making it difficult to infer to which extent neutral trials were indeed perceived as "neutral" (van Steenbergen et al., 2012).

Stürmer and colleagues (2011) took exactly this approach. Participants in their experiment performed a block were only punishment (and no-punishment trials) or reward (and no-reward) trials were presented. Moreover, their reinforcement signals were denoted by abstract colored circles and were made contingent on behavior by means of an adaptive algorithm. In the punishment blocks, only the 25 % slowest response times or erroneous responses were punished, while in the reward block only the 25 % fastest correct trials were rewarded. In line with our predictions, Stürmer and colleagues found an enhanced conflict adaptation effect after reward, as opposed to no-reward trials, but no effect of punishment on conflict adaptation was observed. Instead, punishment signals only slowed down performance on the subsequent trial. Still, although this experiment, to our opinion, used a more appropriate design to test the impact of reinforcement signals on adaptations to conflict, it still contains an important confound. We especially think so, because, prior to their publication, we ran exactly the same experiment, also including an adaptive algorithm. However, although our results demonstrated enhanced conflict adaptation effects after both reward and punishment, we had reason to believe these results were largely confounded with previous performance. Specifically, by only rewarding (or punishing) the 25 % fastest (or slowest) trials, we were not only looking at the effect of previous feedback, but also the effect of previous task-performance. Therefore, we believe that the exact impact of reward and punishment signals on the Gratton effect remains to be investigated. We took on this challenge in Chapters 3, 4, and 5.

Because we were also concerned with the potential individual differences in reward and punishment sensitivity, we employed the BIS/BAS-scales (Behavioral Inhibition System, and Behavioral Approach System; Carver & White, 1994; Franken, Muris, & Rassin, 2005) in each of these Chapters. The BIS and BAS scores have proven to be a valuable instrument in indexing the individual differences in punishment and reward sensitivity respectively, and their influence on cognitive control (Amodio, Master, Yee, & Taylor, 2008; Boksem, Tops, Wester, Meijman, & Lorist, 2006; De Pascalis, Varriale, & D'Antuono, 2010; van Steenbergen, Band, & Hommel, 2009). Moreover, we not only believe that these individual differences can help us towards a better understanding of reinforcement signal modulations (Chapters 3 and 4), but also to unravel information in data that could otherwise be overlooked (Chapter 5).

Performance monitoring and the evaluation of conflict

Recent theorizing on the role of affective variables in cognitive conflict has focused on the aversive nature of cognitive conflict (Botvinick, 2007), suggesting that everyday cognitive conflicts, such as misleading traffic situations or ambiguous instructions, can be perceived as aversive (i.e., lead to frustration). Therefore, it has been postulated that we often try to avoid such situations (the law of least mental effort, Hull, 1943) and this idea was also recently put to the test (Kool, McGuire, Rosen, & Botvinick, 2010). However, although most people will intuitively agree that cognitive conflicts can be frustrating and aversive, we often have no choice but to accept these situations and try to deal with them as efficient as possible. Botvinick (2007) suggests that these aversive signals play an important role in learning and cognitive control. By monitoring information processing and detecting these cognitive conflicts, we can adapt to these situations by choosing the less conflicting option, associated with least mental effort (Hull, 1943). Although Botvinick's theory leaves us with attractive working hypotheses about decision making and avoidance/approach behaviour in free-choice task paradigms, it does not extend to forced-choice conflict tasks, which are often the subject of cognitive control research (Botvinick et al., 2001; Egner, 2008; Verguts & Notebaert, 2008). Crucially, in such tasks, participants often have no choice but to respond to such stimuli, irrespective of their difficulty, in order to proceed to the following trial. Similarly, in our everyday lives, we often have no choice but to overcome inconvenient obstacles to achieve a greater goal. Focusing and only acting upon the aversive nature of these situations would then seem counterproductive and demotivating. We believe that it is within such situations and task designs, that responding to more difficult tasks can actually be perceived as more rewarding than easier tasks.

For example, as a jury-member of this dissertation, you have no choice but to read through this entire dissertation. If we had chosen a less fluent font than Times New Roman, making the reading process more effortful, we have reason to believe that you might have been more easily persuaded by our arguments (Hernandez & Preston, 2013), because of the extra effort you would have to exert during reading. This relates to the concept of learned industriousness (Eisenberger, 1992), stating that people can feel secondarily reinforced by the sensation of high effort. Eisenberger took his inspiration from early behaviorists like John B. Watson and B. F. Skinner, but also recent investigations from the animal learning literature (Clement, Feltus, Kaiser,& Zentall, 2000) suggested that people do experience successfully completing a more effortful task as more rewarding than an effortless task (Alessandri, Darcheville, Delevoye-Turrell, & Zentall, 2008; Klein, Bhatt, & Zentall, 2005; Zentall, 2010) and the subjective experience of engaging in more effortful activity can be experienced as more pleasant (Csikszentmihalyi, Abuhamdeh, and Nakamura, 2005). Therefore, we believe people can also find it more rewarding to complete an incongruent trial than a congruent trial.

We outlined how reward-prediction errors can help us recognize how we set goals and deal with the prospect, or treatment, of rewards and punishments. When applying the concept of reward prediction errors to performance monitoring, similar conclusions can be drawn. For example, in their reward value and prediction model (RVPM) of the anterior cingulate cortex (ACC), Silvetti, Seurinck, and Verguts (2011) provided a neuro-computational account for the affective connotation of conflicting situations. They proposed that incongruent trials evoke negative prediction error signals (negative surprises) in the ACC due to the longer reaction times needed to respond to incongruent stimuli, and to the higher probability of an error response (see also Alexander & Brown, 2011). As a consequence of frequent negative prediction errors, the success (or reward) expectation evoked by an incongruent stimulus is lower than that evoked by a congruent one. Interestingly, the RVPM also predicts that once an incongruent trial is correctly solved, it evokes a positive prediction error signal (positive surprise) that is larger than on congruent trials. This model thus predicts a shift from a negative to a positive prediction error after conflict resolution (i.e., responding correctly to an incongruent stimulus), and interprets the conflict-related ACC activation as the conjoined effect of both negative and positive prediction error signals.

In line with this idea, Satterthwaite and colleagues (2012) recently suggested that people experience intrinsic reinforcement during standard cognitive tasks, even in the absence of a reward manipulation. Using a working memory task, they demonstrated how the ventral striatum, known for its central role in motivation and reinforcement learning, responded to task performance as a function of task difficulty, in the sense that correct responses on more difficult trials resulted in higher ventral striatum activation. Furthermore, Molapour and Morsella (2011) observed that nonsense shapes that co-occurred with incongruent Stroop stimuli were preferred over shapes that co-occurred with congruent or neutral Stroop stimuli. However, the findings of Molapour and Morsella provide at best indirect evidence for the potentially rewarding role of conflict resolution. We therefore set out to examine this issue more directly in Chapter 6.

Conflict-induced exploitation and affect-induced exploration

Earlier, we identified the balancing between exploitation and exploration, or cognitive stability and cognitive flexibility, as being a key aspect of reinforcement learning: In contrast to instructed learning, the agent in reinforcement learning has to rely solely on learning rules, task goals, and its environment, to know when to exploit and when to explore (Sutton & Barto, 1998). This balance has also been acknowledged to play a fundamental role in our daily decision making (Cohen, McClure, & Yu, 2007; Frank, Doll, Oas-Terpstra, & Moreno, 2009). Gittins and Jones (1974) developed an algorithm (the Gittins index) to model this decision making process and while it may be applicable to some paradigms or processes (e.g. Krebs, Kacelnik, & Taylor, 1978), it is far from optimal for explaining human cognitive control behavior (Cohen, McClure, & Yu, 2007).

Within this framework of exploitation versus exploration, we could see the Gratton effect as a manifestation of exploitation. This is commensurate with the adaptation by binding model of Verguts and Notebaert (2008, 2009) that explicitly assumes that task-associations are being strengthened upon conflict experience, thereby enhancing task focus and promoting cognitive stability (exploitation). Although of minor impact in single conflict tasks, this could be at the cost of cognitive flexibility (exploration) in double task environments. As argued above, the Goschke effect (Goschke, 2000) demonstrates just that. By strengthening task-associations after cognitive conflict, participants experience more interference when having to switch tasks on the subsequent trial. Therefore, this effect explicitly demonstrates how adaptations after conflict can be seen as a manifestation of enhanced cognitive stability or exploitation, and will be our measure of interest in Chapter 7.

One promising research area that could help us further understand what drives us to exploit vs. explore comes from the emotion literature. In fact, there are various studies and theories suggesting that this balance is modulated by affect: while positive emotions are thought to broaden attention and enhance cognitive flexibility (Dreisbach, 2006; Easterbrook, 1959; Friedman and Förster, 2010; Isen, 2000), negative emotions enhance task focus and promote cognitive rigidity (Chajut and Algom, 2003; Öhman, Flykt, & Esteves, 2001). Over the course of the last half-century, this literature - investigating the impact of positive vs. negative affect on action, perception, memory and decision making - has expanded enormously. Therefore, we will restrict our discussion of these studies to those that investigated the impact on cognitive control, preferably using trial-to-trial modulations of affect. Most studies looking at the impact of affect on performance used block-wise modulations, investigating the effect of mood on cognitive control (e.g., Birk, Dennis, Shin, & Urry, 2011; Dreisbach & Goschke, 2004; Larson, Gray, Clayson, Jones, & Kirwan, in press; van Steenbergen, Band, & Hommel, 2010; Kuhbandner & Zehetleitner, 2011; Zwosta, Hommel, Goschke, & Fischer, in press) and consistently observed positive affect promoting cognitive flexibility and/or negative affect promoting cognitive stability. However, Gable & Harmon-Jones (2011) argued that this observation is presumably restricted to mood-inductions or post-goal affect. The latter, they reasoned, signals that task goals have been met successfully, loosening task focus toward a more exploratory mode (Carver, 2003; Gable & Harmon-Jones, 2011, van Steenbergen et al., 2009). Post-goal negative affect, on the other hand, has been argued to promote the need for stabilizing the present task-set, directing attention towards the task (e.g., van Steenbergen et al., 2012).

Interestingly, studies that looked at trial-to-trial affect modulations by means of performance-unrelated affective stimuli seem to have reached different conclusions. For example, using affective pictures as non-performance-related "inter-trial-cues", Gable & Harmon-Jones (2008) demonstrated how positive pictures induced a local focus, rather than a global focus (see also Harmon-Jones & Gable, 2009). Similarly, Padmala, Bauer, & Pessoa (2011) showed how non-performance-related negative pictures actually counteracted, rather than enhanced, task-focus (see also

Hart, Green, Casp, & Belger, 2010; Dennis, Chen, & McCandliss, 2008; Melcher, Born, & Gruber, 2011).

Although the difference in results between Padmala et al. (2011) and van Steenbergen et al. (2009, 2010) already suggests that conflict-induced cognitive stability (i.e., the Gratton effect) is promoted after performance-related negative affect, and counteracted after performance-unrelated negative affect, we believe a better measure of conflict-promoted stability is desirable. Moreover, because we cannot know with certainty if the affect signals in the study of van Steenbergen and colleagues were perceived as performance-contingent or not (see above), a more systematic manipulation of performance-contingency is required. Therefore, we will study this, on both a neural and behavioral level, by investigating the affective modulations of the Goschke effect, dependent on performance contingency, in Chapter 7.

THE PRESENT DISSERTATION

By now, we hope to have familiarized the reader with the research domains of "conflict monitoring" and "reinforcement learning", and why we believe notions from the latter might help form a better picture of the former. We outlined some predictions by taking into account reinforcement learning concepts such as Hebbian learning, reward learning, reward prediction errors, and the exploitation/exploration trade/off. In our empirical chapters 2 to 7, we will put those predictions to the test.

Specifically, we argued how the Gratton effect can be seen as a manifestation of conflict-induced Hebbian learning. Verguts and Notebaert (2008, 2009) argued that upon conflict experience, a learning signal, or "now print" signal, is sent throughout the brain strengthening all active associations. This mechanism can explain how adaptations to conflict occur in a task- (Kiesel, Kunde, & Hoffman, 2006; Notebaert & Verguts, 2008), item- (Abrahamse, Duthoo, Notebaert, & Risko, in press; Bugg, Jacoby, & Chanani, 2011; Jacoby et al., 2003; Leboe & Mondor, 2007), and context- (Cañadas, Rodríguez-Bailón, Milliken, & Lupiáñez, 2012; Crump et al., 2006; Crump, Vaquero, & Milliken, 2008; Crump & Milliken, 2009; Heinemann, Kunde, & Kiesel, 2009; King et al., 2012a, 2012b) specific manner. However, we wanted to go one step further, and see if also response modality (Chapter 2), or task-irrelevant salient contexts (Chapter 4), can determine adaptations to conflict. To this end, we employed an effector-switching study (Chapter 2), where a conflict task was randomly assigned to feet responses or hand responses, on a trial-to-trial basis. This way, we could investigate if conflict, detected when performing the task using hands (or feet), would strengthen associations specific to that effector, or generalize across all task-relevant stimulus features. In a second study (Chapter 4), we set out to investigate if task-irrelevant color variations in a visual search context would modulate trial-to-trial adaptations or not.

A second major research question was to see if conflict-induced strengthening of associations could be enhanced by randomly reinforcing successful performance. This would be in line with the century-old idea that reward helps strengthening stimulus-response associations that led to this reward (Thorndike, 1911; Skinner, 1953; Schultz, 2002). We argued that previous studies looking into this endeavor, used reward and punishment signals that where either confounded with affect modulations (van Steenbergen et al., 2009, 2012) or confounded with task performance (Stürmer et al, 2011). Therefore, we administered the following reinforcement schedule. We told participants that they could be rewarded (Chapter 3) or punished (Chapter 5) in only 25 % of the trials (this to keep the reward or punishment expectancy similar across participants). Truly, only 25 % of the trials, randomly assigned, were followed by a reinforcement signal. However, whenever participants responded too slow or incorrect, they did not receive their reward. Similarly, when participants responded very fast and correct, they were relieved from receiving punishment. These respective response-deadlines in both experiments were set so that participants only missed out on their rewards, or could escape the punishments, on 10% of the feedback trials. This way, reinforcement signals were still performance-contingent, yet randomly distributed, assuring that we could investigate the effects reinforcement signals themselves on adaptations to conflict. In Chapter 3, we investigated the effects of reward on both the Gratton and Goschke effect, and in Chapter 5, we tested the effects of punishments on the Gratton effect.

In Chapter 4, we tested the effects of reward on the Gratton effect, depending on task-context. Specifically, we took an integrative approach by testing both our context-specificity hypothesis (Chapter 2) and reward manipulation (Chapter 3) within one experiment. To this end, we used a hybrid visual search/flanker task, largely inspired on a paradigm of Hickey and colleagues (2010). The reward procedure was much the same as the procedure for Chapter 3, but slightly differed in that now on 50% of the trials, instead of 25% of the trials, a high reward could be obtained. On the other 50% of the trials, correct performance was always followed by low reward. Although the details of this experiment will be explained in Chapter 4, the motivation for this study was to see if reward enhances adaptations to conflict in a conflict-specific manner. If reward, much like conflict, enhances associations selectively, we can expect an enhanced Gratton effect after high reward on context repetitions, but not on context alternations. Not only did we expect that the Gratton effect would be enhanced after high rewards on context repetitions only, we also predicted a reversed pattern after low reward. In line with the studies of Hickey et al. (2010) and Della Libera and Chelazzi (2009), demonstrating enhanced focus to distractor features after low reward, we expected that the Gratton effect after low reward would be enhanced on context alternations, relative to context repetitions. This is also consistent with a more general literature on win-stay lose-shift mechanisms in decision making (Bussey, Wise, & Murray, 2001; Evenden, & Robbins, 1984; Genovesio, Brasted, & Mitz, 2005; Melis, Hare, & Tomasello, 2006; Nowak, 2006; Nowak & Sigmund, 1993; Posch, 1999).

In investigating the influence of reinforcement signals in Chapters 3, 4, and 5, we were also interested in the effects of individual differences in reward and punishment sensitivity thereon. This was indexed by administering the BIS/BAS-scales, measuring punishment and reward sensitivity respectively. While we expected to see that reward-sensitivity would help enhancing the beneficial effects of reward on (context-sensitive) adaptations to conflict, we predicted a reversed pattern for punishment sensitivity. This is motivated by the idea that punishment signals are generally experienced as more salient than reward signals. Consistently, Gomez and McLaren (1997) and Tranel (1983) demonstrated how punishment schedules (as opposed to reward schedules) induced higher overall arousal levels, as measured by the skin conductance response. We believe this might help explain why Stürmer and colleagues observed an overall slowing, rather than enhanced Gratton effect, after punishment, and will illustrate how punishment sensitivity could play an important role therein.

As a third research hypothesis, we suggested that trough the process of reward prediction errors, people may perceive successfully overcoming a conflict trial as more rewarding than successfully responding to a congruent trial. This is motivated by the idea that upon stimulus presentation, people are being cued about their outcome expectancy (congruent trials have a higher chance of being correctly responded to than incongruent trials), as indicated by the experience of more negative affect upon perceiving incongruent stimuli (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, in press). However, when having correctly responded to these stimuli, the RVPM (Silvetti et al., 2011) predicts that the positive prediction error will be greater for incongruent, than congruent, stimuli, suggesting that following correct responses, incongruent trials are being perceived as more "positive".

Consistent with this idea, we described a series of studies in animal cognition conducted by the group of Thomas Zentall, all demonstrating a bigger preference for rewards following more effortful tasks in pigeons, primates and humans. Using the stimuli-set from Klein and colleagues (2005), we ran a four colour Stroop task (n=33) where each Stroop trial was followed by a picture discrimination task. Zentall’s studies showed how these pictures were preferred as a function of the effort needed to obtain them. Similarly, in a test phase, we examined if pictures associated with “correctly responding to incongruent trials” were more preferred to pictures associated with “correctly responding to congruent trials”, in both a picture choice task and a picture rating scale. However, choice rates in the picture choice task did not reveal any significant effects: our hypothesis was not confirmed (although the picture rating scale showed a trend towards a bigger preference for incongruent correct items, this trend did not reach significance). Still, it could be that this paradigm was unfit to test our main idea. We assumed that, in line with the work of Thomas Zentall, the picture preference would tell us something about the rewarding aspect of the associated task, but this assumption might be wrong. Alternatively, this measurement could be considered too subtle and indirect. In resolving this issue we took a different, more direct, approach by using an affective priming paradigm (see also Aarts, De Houwer, & Pourtois, 2012; Dreisbach & Fischer, 2012a; Fritz & Dreisbach, in press). This paradigm, and its results are described in Chapter 6. This complete study was a joint collaboration with my colleague PhD student Nathalie Schouppe, who is interested and specialized in studying the affective qualities of cognitive conflict.

Lastly, Chapter 7 was set up to investigate the influence of positive versus negative affect on conflict-induced cognitive stability, depending on the performance-contingency of the affect signals. We argued that performance contingency might play a crucial role in the effects of affect on cognitive control (see also Gable & Harmon-Jones, 2011; Kanske, 2012). This was especially motivated by the fact that the only two studies having investigated the effect of trial-to-trial variations in affect (Padmala et al., 2011; van Steenbergen et al., 2009, 2012) obtained contradictory results.

Moreover, the performance-contingency in the studies of van Steenbergen and colleagues has been put into question (Dreisbach & Fischer, 2012b). Therefore, by systematically manipulating performance contingency, we investigated its influence on the affective modulation of the Goschke effect. Also, because neurophysiologic models of affective modulations of cognitive control (Aarts, Custers, & Veltkamp, 2008; Ashby, Isen, & Turken, 1999; Gray, 2001; Pessoa, 2008, 2009; Shackman et al. 2011; for a review, see Chiew & Braver, 2011) do not take into account the role of task-relevance or performance-contingency, it remains to be investigated to which extent task-relevant and -irrelevant affective modulations of cognitive control rely on the same neurophysiologic pathways and brain structures, and where they might diverge. Therefore, by paring this task-switching experiment with fMRI, we will be able to identify the brain regions associated with the Goschke effect, and which regions are differentially employed as a function of our affective manipulations.

Please note that all these chapters are written as independent studies. Therefore, in our last chapter, Chapter 8, we will try to integrate and discuss the findings brought forward in these studies in a "General discussion", by linking back to the general framework of this dissertation as outlined in this introduction. In this discussion, we will devote special attention to the divergent effects of affect and reinforcement signals, but also why, although introduced as separate entities, there is often a thin line between both. Moreover, we will speculate how neuromodulatory systems might have helped in bringing about the hereafter discussed results and what other measures or paradigms might be desirable for future research.

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CHAPTER 2
CONFLICT ADAPTATION BY MEANS OF ASSOCIATIVE LEARNING[1]

Cognitive control is responsible for adapting information processing in order to carry out tasks more efficiently. Contrasting global versus local control accounts, it has recently been proposed that control operates in an associative fashion, that is, by binding stimulus–response associations after detection of conflict (Verguts & Notebaert, 2009). Here, this prediction is explicitly tested for the first time. In a task-switching study where both tasks use the same relevant information, we previously reported conflict adaptation over tasks (Notebaert & Verguts, 2008). In the current experiment, we demonstrate that this is restricted to conditions where both tasks use the same effectors, thereby supporting the associative control account.

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[1] Braem, S., Verguts, T., & Notebaert, W. (2011). Conflict adaptation by means of associative learning. *Journal of Experimental Psychology: Human Perception and Performance, 64*, 1662-1666.

INTRODUCTION

In everyday life, we frequently need to control the incoming information to avoid conflicting responses. For example, cognitive control directs our attention to the instructions of a traffic agent, when traffic lights tell differently. In the laboratory, one of the most prominent control effects is the observation that the influence of irrelevant stimulus information is reduced after a trial where conflict occurred. This effect (the Gratton effect) was originally observed by Gratton, Coles and Donchin (1992) reporting a smaller flanker effect after incongruent (> < >) than after congruent trials (> > >). The Gratton effect has been reproduced in other congruency tasks like the Simon (Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Notebaert & Verguts, in press) and the Stroop task (Kerns et al., 2004).

An open question is to what extent cognitive control generalizes across tasks and settings. Regarding the implementation of control, different positions can be distinguished. First, cognitive resources may be elevated when conflict is detected. Kahneman (1973) suggested that when encountering a response conflict, a state of generalized alertness is induced. This state consists of a combination of inhibition and increased arousal. This recruitment of cognitive resources is not specific to the current task or setting, but instead generalizes across different tasks and task settings.

In contrast, recent theoretical accounts introduced a more local implementation of conflict adaptation. For example, in their conflict monitoring theory, Botvinick, Braver, Barch, Carter and Cohen (2001) propose that response conflict triggers an adaptive mechanism that enhances task-specific processes. In a flanker task, conflict increases the processing of targets and decreases the processing of flankers; in a Stroop task, conflict enhances colour processing and reduces word processing. Note that not all cognitive control processes should be task-specific to belong to the local control category; for example, conflict monitoring theory explicitly assumes that conflict detection extends across tasks. However, because the implementation of control occurs at the (local) level of the task-relevant dimension (increasing attention to that dimension), we categorize conflict monitoring theory as a local control model.

Local control can be implemented in different ways. Recently, it was proposed that the conflict adaptation effect might arise from modulation of task-relevant associations (Blais, Robidoux, Risko, & Besner, 2007; Davelaar & Stevens, 2009; Verguts & Notebaert, 2008; 2009; see also Spapé & Hommel, 2008). For example, Verguts and Notebaert (2008, 2009) argued that response conflict leads to arousal, which itself leads to binding active representations more strongly. Since task-relevant representations are usually more active than task-irrelevant representations, task-relevant associations will tend to be more strongly modified, providing an implementation of local control.

In earlier work, we already refuted global control and demonstrated that control is more local (Notebaert & Verguts, 2008). In the study of Notebaert and Verguts (2008), two tasks were intermixed. In one condition, the relevant information was the same for the two tasks, while in the other condition, the relevant information was different for the two tasks. We found conflict adaptation across tasks when the relevant information was the same, whereas no conflict adaptation was found when the relevant information differed, supporting the idea of local control.

Here, we further investigate the implementation of local control by focusing on the role of task-relevant associations. For that purpose, we developed a design in which conflict adaptation can be investigated across different stimulus-response associations. Previously, we focused on the locality of conflict adaptation by distinguishing tasks with shared versus different relevant stimulus dimensions (Notebaert & Verguts, 2008); in the current paper, we distinguished tasks with the same relevant information by assigning different effectors to the two tasks. Instead of the SNARC and Simon task as in Notebaert and Verguts (2008), two variations of the Simon task were used, so the two tasks had the same relevant and irrelevant stimulus characteristics. If local control is implemented by assigning more attention to the task-relevant stimulus dimension, a Gratton effect should be obtained within as well as across effectors. In contrast, if local control operates at the level of stimulus-response associations, a Gratton effect should be obtained within tasks but not across tasks.

EXPERIMENT 1 AND 2

Our design is represented in Figure 1 (a) and (b). We used a vertical and horizontal Simon task. The two tasks shared relevant and irrelevant stimulus dimensions. Participants responded to the orientation of the stimuli. Stimuli were presented on the left or right side and above or below the fixation cross. The Simon effect is the observation that responses are faster when stimulus and response locations correspond spatially, although the stimulus location is irrelevant (Simon, 1969). In Experiment 1 different effectors were assigned to the horizontal and the vertical Simon task. Experiment 2 served as a control experiment to verify that conflict adaptation can be obtained from a horizontal to a vertical Simon task (or vice versa) when the same effectors are used for the two tasks.

Method

Participants

38 students took part for a small fee of 6€, 19 subjects per experiment (Experiment 1: range = 19-24 years, 16 female, 16 right-handed; Experiment 2: range = 18-24 years, 17 female, all right-handed).

Stimuli

For both experiments, the stimuli consisted of the character ‘X’ printed in yellow or red. The ‘X’ was always presented below or above and left or right from the fixation cross, corresponding to the four corners of an imaginary square surrounding the fixation point. The stimuli were presented upright or in italic (tilted 20° to the right). In total, there are 16 different stimuli (2 × 2 × 2 × 2): X, below or above and left or right from the fixation point, presented upright or in italic, in yellow or red. The stimuli were approximately 0.5 cm high and 0.5 cm wide (visual angle 0.6° × 0.6°) and always presented 1.2 cm above/below and 1.2 cm to the right/left of the fixation cross.

Procedure

Participants were asked to respond to the orientation of the stimuli, whereas stimulus colour served as an indicator for the appropriate response mapping. In Experiment 1, one fourth of the participants had to respond with the upper hand when the yellow ‘X’ was in italic and with the lower hand when the yellow ‘X’ was presented upright. They had to press the right foot when the red ‘X’ was in italic and left foot when the red ‘X’ was presented upright. In a second condition this response mapping was reversed. The third and fourth conditions were the same except that the stimulus colours were interchanged (e.g., in condition 3, right foot for italic yellow ‘X’ and upper hand for italic red ‘X’). Half of the participants had to use their right hand as upper hand, and left hand as lower hand. For the other half, this hand placement was reversed. Participants were randomly assigned to one of the eight conditions (hand placement × response mapping). In Experiment 2, participants had to use the keys ‘1’, ‘3’, ‘7’ and ‘9’ on the number pad of a keyboard to respond. One fourth of the participants had to respond with the upper keys (‘7’ and ‘9’) when the yellow ‘X’ was in italic and with the lower keys (‘1’ and ‘3’) when the yellow ‘X’ was presented upright. They had to press the rightmost keys (‘9’ and ‘3’) when the red ‘X’ was in italic and the leftmost keys (‘7’ and ‘1’) when the red ‘X’ was presented upright. In a second condition this response mapping was reversed. The third and fourth conditions were the same except that stimulus colours were interchanged (e.g., in condition 3, rightmost keys for italic yellow ‘X’ and upper keys for italic red ‘X’). The two keys had to be pressed simultaneously with a maximum delay of 200 milliseconds between the two presses. Participants were randomly assigned to one of the four conditions.

In each Experiment, a block contained 160 trials. The trials were presented in a random order without replacement, meaning all 16 stimuli were presented 10 times. Five blocks were presented. The response-stimulus interval (RSI) was 800 milliseconds. During the RSI, a fixation cross was presented. Stimuli remained on the screen until the participant responded. The maximum response time (RT) was 5000 milliseconds.

The stimuli were presented on a Pentium, with the use of Tscope software (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 2006). In Experiment 1, a keyboard and a foot response box were used. On the keyboard, numbers ‘2’ and ‘8’ functioned as the lower and upper button. For the foot responses, participants were asked to take off their shoes. Before the actual experiment took place, they received some practice with the response box in an unrelated discrimination task. In Experiment 2, only a keyboard was used.

Results

Experiment 1

Three participants were excluded from the analysis because of a misunderstanding of the response mapping (7, 45 and 49% accuracy). The remaining 16 participants obtained much higher accuracy rates (*M* = 91%; *SD* = 0.03). Because subjects needed some time to get used to the setup, the first block was treated as a practice block and thus excluded from the analyses. Trials following an error and the first trial of each block were also removed from further analyses. For the RT analyses, errors were also excluded (8.9%). From the remaining trials, RT outliers (± 2 *SD*) were removed (another 4.1%).

We carried out an ANOVA with four within-subject factors (congruency, previous congruency, task sequence (repetition or alternation from trial *n*-1 to *n*) and orientation sequence (repetition or alternation from trial *n*-1 to *n*) on RTs and error rates. The variable orientation sequence was included to investigate the influence of repetitions on the Gratton effect (Hommel, 2004; Mayr, Awh, & Laurey, 2003; Nieuwenhuis, 2006). Overall, there was a significant congruency effect ($F(1, 15) = 9.857$, $p < 0.01$) and a task switch effect ($F(1, 15) = 47.405$, $p < 0.001$). This effect did not interact with previous congruency ($F(1, 15) < 1$, ns.). Importantly, there was a three-way interaction between task sequence, congruency and previous trial congruency, $F(1, 15) = 12.012$, $p < 0.01$. As depicted in Figure 1 (c), this indicates that the Gratton effect is only observed for task repetitions ($t(15) = 3.204$, $p < 0.01$), whereas for task alternations, a reversed Gratton effect was observed ($t(15) = 2.359$, $p < 0.05$).

The four-way interaction between orientation sequence, task sequence, congruency and previous trial congruency was not significant ($F(1, 15) = 2.798$, $p > 0.1$), indicating no moderating effects of orientation repetitions. Hence, our results cannot be explained by means of mere stimulus/response repetition across trials (Mayr et al., 2003). Taken together, these analyses indicate that conflict adaptation was only observed when the task was the same in the two consecutive trials.

The error rates analyses showed no interaction between task sequence, congruency and previous trial congruency ($F(1, 15) = 1.511$, $p > 0.1$), nor an overall Gratton effect ($F(1, 15) = 1.801$, $p > 0.1$).

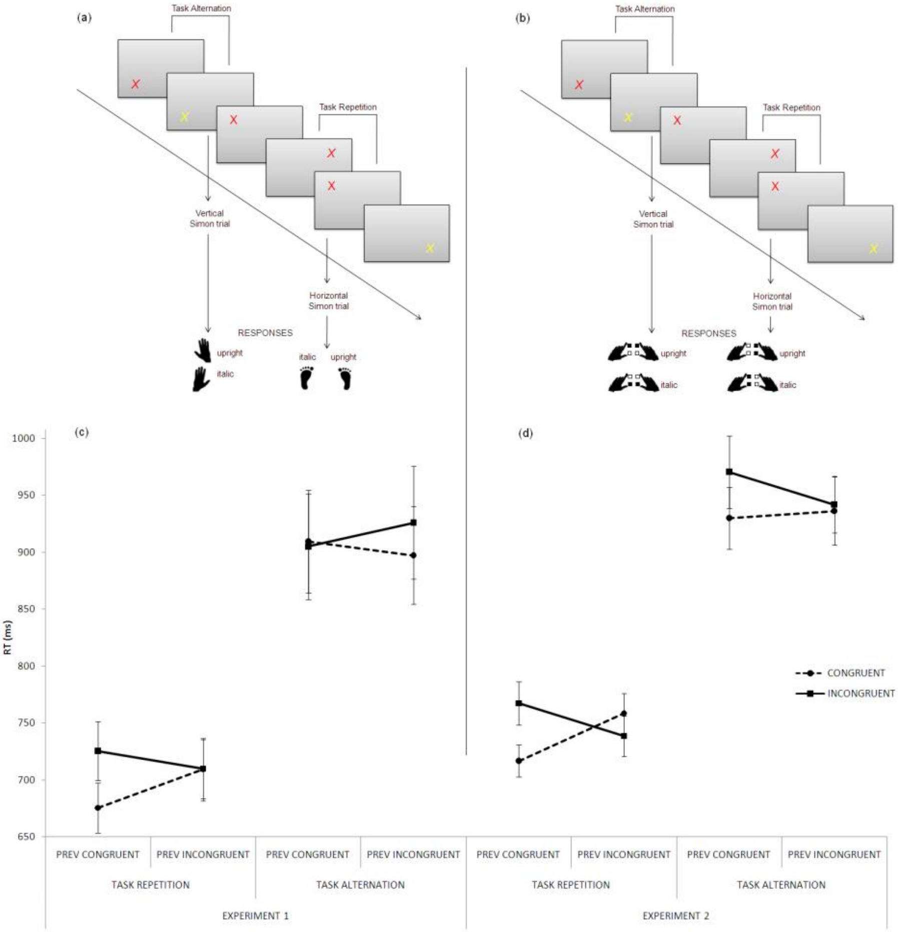

Figure 1. (a) The design of Experiment 1 in which vertical and horizontal Simon trials are assigned to different effectors (hands and feet, respectively). **(b)** The design of Experiment 2 in which vertical and horizontal Simon trials are assigned to the same effectors. In the lower half of the figure are the reaction times for Experiment 1 **(c)** and Experiment 2 **(d)**. Dotted lines indicate congruent trials and full lines indicate incongruent trials. The error bars are ± 1 standard error.

Experiment 2

In this second experiment, we aimed at replicating the results of Notebaert and Verguts (2008) where conflict adaptation across tasks was observed when the tasks shared relevant stimulus information and effectors. The only difference is that here we used a horizontal and vertical Simon task, as in Experiment 1. Two participants were excluded from the analysis because of a misunderstanding of the response mapping (0 and 51% accuracy). The remaining 17 participants showed much higher accuracy rates (*M* = 89%; *SD* = 0.05). Again, the first block was treated as a practice block and thus excluded from the analyses. Trials following an error and the first trial of each block were also removed from further analyses. For the RT analyses, errors were also excluded (11.3%). From the remaining trials, RT outliers (± 2 *SD*) were removed (another 4.3%).

We carried out the same ANOVA as for Experiment 1 on both RTs (the time between the stimulus onset and the second response) and error rates. Again, a significant congruency effect was observed ($F(1, 16) = 25.320$, $p < 0.001$), as wells as a task switch effect ($F(1, 16) = 123.105$, $p < 0.001$). There was an overall Gratton effect ($F(1, 16) = 28.413$, $p < 0.001$), which did not interact with task sequence ($F(1, 16) = 2.783$, $p > 0.1$). As depicted in Figure 1 (d), this indicates that a Gratton effect is observed for both task repetitions ($t(16) = 6.151$, $p < 0.001$) and task alternations ($t(16) = 2.040$, $p = 0.058$). The four-way interaction between orientation sequence, task sequence, congruency and previous trial congruency was not significant ($F(1, 16) = 1.244$, $p > 0.1$).

The error rates analyses showed an overall Gratton effect ($F(1, 16) = 8.001$, $p < 0.05$), but no interaction between task sequence, congruency and previous trial congruency ($F(1, 16) < 1$, ns.).

Experiment 1 vs. 2

In order to investigate the differences in Gratton effects across experiments, ANOVAs were conducted for both task repetitions and task alternations separately, with experiment as a between-subjects factor (cf. Notebaert & Verguts, 2008). For task repetitions, there was a significant overall Gratton effect ($F(1, 31) = 39.502$, $p < 0.001$), but there were no differences in Gratton effect between the two experiments (three-way interaction of experiment, congruency and previous trial congruency, $F(1, 31) = 1.187$, $p > 0.1$), nor was there a four-way interaction between experiment, congruency, previous trial congruency and orientation sequence ($F(1, 31) < 1$, *ns.*). Crucially, however, for task alternations, experiment did interact with congruency and previous trial congruency $F(1, 31) = 9.326$, $p < 0.01$), indicating a significant difference in conflict adaptation for task alternations in Experiment 1 (reversed Gratton effect) versus Experiment 2 (Gratton effect). Again no four-way interaction between experiment, congruency, previous trial congruency and orientation sequence was observed ($F(1, 31) < 1$, *ns.*).

The error rates analyses showed an overall significant Gratton effect ($F(1, 31) = 11.810$, $p < 0.05$) for task repetitions, but no other significant interaction of interest (all $p > 0.25$).

DISCUSSION

By assigning different effectors to different stimuli, the current study examined the level at which conflict adaptation takes place. The results indicate a substantial difference between effector repetitions and alternations; in fact, a reversed Gratton effect was observed for effector alternations. Furthermore, we did observe conflict adaptation across tasks when both tasks shared effectors (Experiment 2) indicating that the reverse Gratton effect in Experiment 1 can be attributed solely to the different effectors for the two tasks. This study is consistent with a number of recent findings illustrating the contextual modulation of cognitive control (Crump, Gong, & Milliken, 2006; Crump & Milliken, 2009; Jacoby, Lindsay, & Hessels, 2003; Spapé and Hommel, 2008). The current paper provides steps towards unravelling its underlying mechanism by demonstrating the importance of stimulus-response associations.

These results challenge global control models, but also local control models that emphasize the input from task representations to the stimulus input layer (e.g., Botvinick et al. 2001; Verguts & Notebaert, 2008). They are however, consistent with the more general adaptation by binding framework (Verguts & Notebaert, 2009) which posits the importance of interactions between conflict processing and task-relevant (including stimulus-response) associations for the implementation of cognitive control.

It may be argued that also Egner & Hirsch’ (2005) cortical amplification hypothesis can be challenged by our results. Following conflict, Egner and Hirsch observed increased cortical activity in the area responsible for processing task relevant information. Their hypothesis assumes increased processing of task-relevant information after conflict, irrespective of the effectors used. However, as argued in Egner (2008), this hypothesis is specific to tasks where conflict originates from overlapping stimulus dimensions (e.g., Stroop task, flanker task). It is therefore an interesting question for future research whether the same results as reported here can be obtained in Stroop or flanker tasks.

In both experiments, a considerable task-switch cost was observed. As noted by Egner (2008), such task switch costs might interact with conflict adaptation effects. However, the possible “task set reconfiguration” occurring at such a switch trial cannot account for the observation that the Gratton effects for task alternations differed significantly between Experiment 1 (reversed Gratton) and Experimen 2 (Gratton). This reversed Gratton effect in Experiment 1 can however be explained in terms of adaptation by means of associative learning. Assuming there is competition between the two effectors, stimulus-response associations for one effector will be weakened when stimulus-response associations for the other effector are strengthened. For a similar reason, Verguts and Notebaert (2008) obtained a reverse Gratton effect in their computational model when the relevant input dimensions were different in previous and current trial (see also Notebaert & Verguts, 2008). However, this explanation for the reversed Gratton effect needs further empirical investigation.

Other experiments resemble our setup in the sense that different effectors were used to respond to the same relevant information (Experiment 3, Freitas et al., 2007; Experiment 1, Akçay & Hazeltine, 2008) or different relevant information (Experiment 2, Freitas et al., 2007). These authors did find conflict adaptation across response mappings. There is an important difference with our Experiment 1 however: our subjects switched between hand and foot responses, while their subjects switched between left and right hand responses (Akçay & Hazeltine, 2008), different directions in their responses with a joystick (Experiment 3, Freitas et al., 2007) or different vocal responses (Experiment 2, Freitas et al., 2007). Hence, the response sets were much more similar across the two tasks in these studies. From an associative point of view, one would indeed predict more generalization across tasks when the tasks exhibit more overlap. To settle this issue, however, more studies are needed in which the amount of similarity between tasks is parametrically manipulated.

One may wonder whether associative control can really be considered as an instantiation of cognitive control. Associations have the connotation of being fast and effortless; exactly the opposite of cognitive control, which is typically thought to be slow and effortful. However, cognitive control is needed to optimize task performance, and whether this optimization process is fast or slow is not relevant for its definition. In fact, it might be argued that cognitive control is more efficient when it takes place fast and without effort. Riding on the back of associative learning processes would then seem to be an excellent option with the benefit of control being relatively specific: After all, there is no reason in putting on gloves, when only your feet are cold.

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CHAPTER 3
REWARD MODULATES ADAPTATIONS TO CONFLICT[1]

Both cognitive conflict (e.g. Verguts & Notebaert, 2009) and reward signals (e.g. Waszak & Pholulamdeth, 2009) have been proposed to enhance task-relevant associations. Bringing these two notions together, we predicted that reward modulates conflict-based sequential adaptations in cognitive control. This was tested combining either a single flanker task (Experiment 1) or a task-switch paradigm (Experiment 2) with performance-related rewards. Both experiments confirmed that adaptations after conflict were modulated by reward. In the flanker task, this resulted in increased conflict adaptation after rewarded trials. In the task-switching experiment, reward increased the conflict-modulated switch cost. Interestingly, both adaptations to conflict disappeared after no-reward trials. Moreover, individual differences in participants' sensitivity to reward predicted these reward modulations of trial-to-trial adaptations. These findings shed new light on the exact role of cognitive conflict in shaping subsequent behaviour.

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[1] Braem, S., Verguts, T., Roggeman, C. & Notebaert, W. (2012). Reward modulates adaptations to conflict. *Cognition, 125,* 324-332.

INTRODUCTION

Daily routines are repeatedly interrupted by conflicts. Efficiently dealing with these conflicts is referred to as cognitive control. For instance, the sound of booing fans can interfere with a sports player's actions, but subsequent adaptations to such interruptions assist us in maintaining our goals (i.e., winning the game). When it comes to reaching such goals, reward is a great motivator (Skinner, 1953); receiving a trophy will encourage us to efficiently repeat effective actions later. In this study, we investigate this influence of reward on cognitive control.

Cognitive control is typically studied with conflict tasks where irrelevant information slows down processing of relevant stimulus information. In the flanker task (Eriksen & Eriksen, 1974), where the central target is presented with either congruent (> > >) or incongruent (> < >) flankers, participants respond faster on congruent trials, as compared to incongruent trials. Importantly, participants adapt their performance based on these incongruent trials. Gratton, Coles, and Donchin (1992) observed that there was a smaller flanker effect after incongruent than after congruent trials. Similarly, it has been demonstrated that cognitive conflict enhances the task-switch cost (Brown, Reynolds, & Braver, 2007; Goschke, 2000), the decrease in performance associated with switching between two tasks, compared to repeating the same task. Participants showed larger task-switch costs after incongruent than after congruent trials.

According to the adaptation-by-binding model of Verguts and Notebaert (2008; 2009), both effects can be conceptualized as strengthening of associations due to conflict. In this model, conflict detection on incongruent trials increases task-relevant connections, increasing the focus on task-relevant information. By binding these associations after conflict, a smaller congruency effect will occur on the following trial. Likewise, increased connections improve task performance when a task is repeated but hinder task performance when the task changes, causing the modulation of the switch cost.

Although the hypothesis that conflict enhances associations is fairly recent, it has been long known that reward strengthens task-relevant associations. Thorndike’s (1911) Law of Effect stated that stimulus-response episodes are more likely to re-occur when followed by reward. Therefore, Skinner (1953) suggested that reward strengthens preceding or ongoing associations. In line with this half-century-old idea, two recent experiments demonstrated how reward increased both short- (Colzato, van Wouwe, & Hommel, 2007) and long-term (Waszak & Pholulamdeth, 2009) binding effects. By presenting positive pictures after correct responses, they demonstrated how rewarded stimulus-response associations can facilitate future task performance.

Since cognitive conflict and reward may act in a similar fashion, we decided to investigate the interactions between conflict-based and reward-based adaptations. We delivered performance-related reward in cognitive control tasks and hypothesized that conflict-based adaptations would be modulated by reward. Since we were planning to investigate the after-effects of reward signals, we expected that the effect of reward would depend on subjects’ reward sensitivity as measured by the BAS Reward Responsiveness Subscale questionnaire (Carver & White, 1994). This scale measures the impact of rewards on a subject’s feelings and motivations; for example, a typical question in this subscale is “When I get something I want, I feel excited and energized”.

EXPERIMENT 1

To test whether reward modulates the adaptation to conflict in congruency effects, we combined a four-choice colour flanker experiment with reward signals in 25% of the trials. Participants did not receive reward when the response was too slow or incorrect. This way, reward signals were both randomly distributed and performance-related. A second group of subjects was assigned to a control condition to ensure that the observed modulations were due to the rewarding aspect of the learning signal, not just its frequency (Notebaert et al., 2009).

Method

Participants

Forty-four students took part in return for credits or 6€ (range = 17-22 years, 35 female, 41 right-handed, 22 participants per condition).

Stimuli

Stimuli consisted of three squares: horizontally aligned, centrally presented and printed in one of the four possible colors (green, yellow, blue or red). Both flankers had either the same or a different color than the central square.

Procedure

The participants responded to the color of the centre square by pressing one of four horizontally aligned response buttons using their index and middle fingers. Subjects were randomly assigned to one of four response mappings, which were created by shifting the response mapping. Each block contained 48 trials. An equal number of congruent and incongruent trials were presented randomly: 25% of the trials were reward trials, which were randomized for the congruent and incongruent trials separately. After practice, participants performed 14 experimental blocks. Between blocks was a self-paced break in which the participants could see their updated score. Every ten participants, the subject with the best score received a store coupon worth 10€. All subjects were truthfully instructed about the reinforcement schedule; they were aware that rewards could only be gained on one out of four trials and that these reward trials were randomly distributed and not cued. Participants also knew that a winner would be selected per group of ten subjects, in order to control for global reward expectancies about the total number of subjects.

A fixation cross was presented, after which stimuli remained on the screen until the participant responded. The maximum response time (RT) was 1000 milliseconds. On reward trials, the participant was given feedback in the form of “+1” presented centrally on the screen for 500 milliseconds, unless he or she did not respond correct or within the maximum response time. In the latter case, or after a “no-reward” trial, a blank screen was presented for 500 milliseconds. Participants knew that only when “+1” was presented, they scored an extra point. Finally, a blank screen was presented for 1000 milliseconds. The between-subjects control condition was identical to the original experiment, except for the removal of the reward schedule, and the reward signal now being replaced by a meaningless stimulus (“@”).

Questionnaires

Six months after the experiment, participants from the experimental condition were contacted with the request to fill in an online version of the Behavioural Inhibition System/Behavioural Activation System (BIS/BAS) Scales (Carver & White, 1994): 15 out of 22 participants responded to this request.

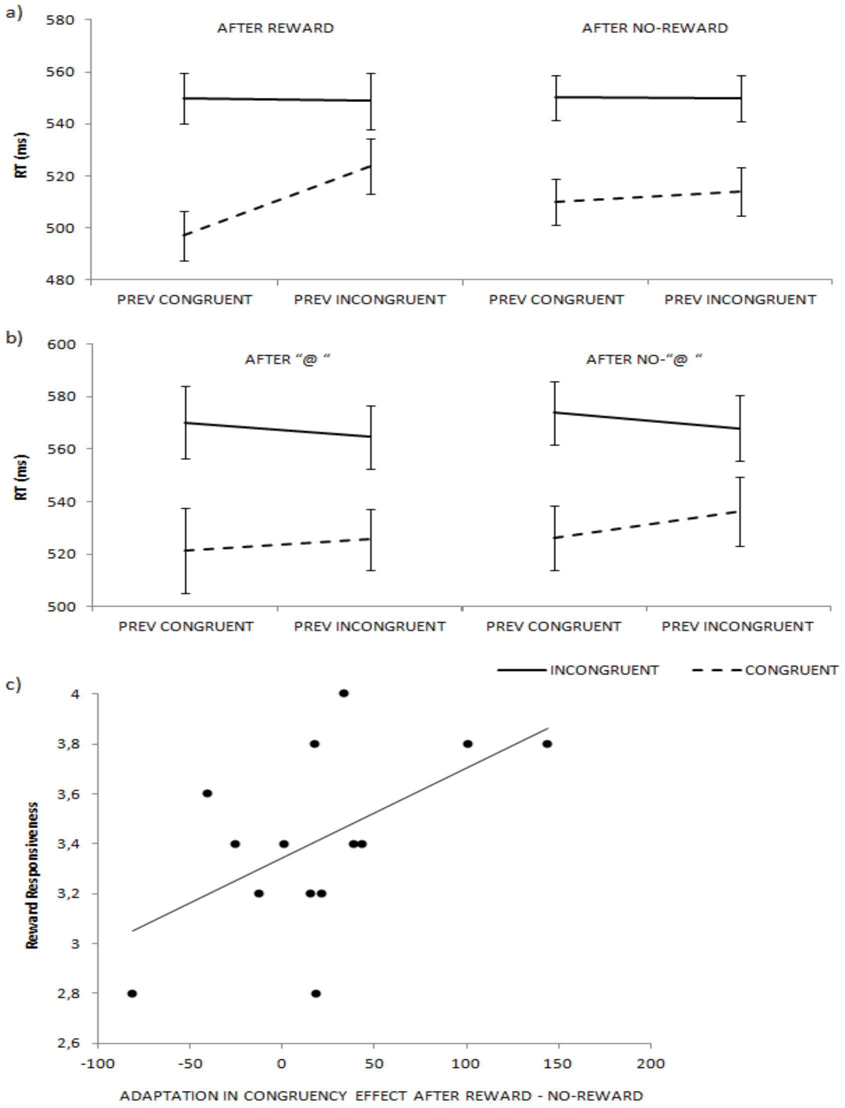

Figure 1. Response times for Experiment 1, reward feedback condition **(a)**; and neutral feedback condition **(b)**. The figure demonstrates how reward modulated the conflict-modulated congruency effect. Below, the scatter plot shows the correlation between individual scores on the BAS-Reward Responsiveness scale and the difference scores for the conflict-modulated congruency effects **(c)**. The error bars are ± 1 standard error.

Results and Discussion

In each feedback condition (reward and neutral “feedback”), a participant was excluded because accuracy was two standard deviations below the group average (group averages: *M*=0.90; *SD*=0.07 and *M*=0.85; *SD*=0.10). Trials following errors and the first trial of each block were removed. For RT analyses, errors were also excluded. From the remaining trials, RT outliers (±2*SD*) were removed (3.3%). We carried out an ANOVA with three within-subject factors (congruency, previous-congruency and previous-feedback) and the between-subjects factor feedback condition, on RTs and error rates.

There was a significant congruency effect, *F*(1,40)=430.429, *p*<.001, which interacted with previous-congruency, *F*(1,40)=18.027, *p*<.001, indicating a significant conflict adaptation effect. A four-way interaction between feedback condition, previous-feedback, congruency and previous-congruency pointed at diverging effects of the different “feedback” stimuli, *F*(1,40)=4.713, *p*<.05. In the reward condition, there was a conflict adaptation effect, *F*(1,20)=13.620, *p*<.01, which interacted with previous-feedback, *F*(1,20)=4.953, *p*<.05. As can be seen in Figure 1a, the conflict-modulated congruency effect is larger after reward trials (subtracting the congruency effect after incongruent from the congruency effect after congruent trials: 28ms), than after no-reward trials (4ms). There was no main effect of previous-reward, nor an overall larger congruency effect after reward (both *F*(1,20)<1). In the neutral condition, a significant conflict adaptation effect was observed, *F*(1,20)=6.016, *p*<.05, which was not modulated by the irrelevant stimulus (*F*(1,20)<1, Figure 1b, 10ms after “@” and 16ms after blank screen). Error rates only revealed a significant congruency effect, *F*(1,40)=27.535, *p*<.001.

As predicted, the differences in conflict adaptation effects (conflict-modulated congruency effect after reward minus after no-reward) correlated with the BAS-Reward-Responsiveness subscale (r=.553, *p*<.05, Spearman's ρ=.460, p=.090, Figure 1c). Moreover, the differences in these effects correlated with the other BAS subscales (BAS-Drive, r=.490, *p*=.075, ρ=.499, p=.069; BAS-Fun-Seeking, r=.541, *p*<.05, ρ=.482, p=.081). No correlations were observed with the BIS-scale (all p>.1).

To rule out the effects of feature repetition and/or integration effects (e.g., Hommel, Proctor, & Vu, 2004) in explaining the reward modulation of adaptations to conflict, we reanalyzed our data by means of multiple regression (Notebaert & Verguts, 2007). To account for between-subjects variance, a multiple regression analysis is performed for each participant separately. Subsequently, the average of each coefficient across participants is tested with a one-sample t test (Lorch & Myers, 1990). In this way, we can test if our crucial interaction between previous reward, previous congruency, and congruency (in the reward condition), remains after controlling for feature repetition and/or integration effects. Along with our previously reported variables of interest, we added five binary (0 or 1) bottom-up factors (see Notebaert & Verguts, 2007), to our multiple regression analysis with reaction time as the dependent variable. The first factor was the repetition of the target, and the second repetition of the flanker. The third factor, called feature integration, codes for complete repetitions and alternations (1) versus partial repetitions (0). The last two factors were respectively negative priming (distractor–becomes-target repetition) and target–becomes-distractor repetition. On top of those factors, we also chose to control for the interactions between previous reward and each of those factors. The analyses show that our main interaction of interest, between previous reward, previous congruency and congruency, can still be observed, t(20)=1.874, *p*=.076. This, after controlling for all the effects of feature repetition and their interaction with previous reward. The main effects of feature integration, target repetition, flanker repetition, and negative priming, all reached significance (all *p*<.05). Additionally, there was a significant interaction between target repetition and previous reward, t(20)=3.564, *p*<.05, indicating a stronger target repetition effect, when the previous trial was rewarded (see also Hickey, Chelazzi, & Theeuwes, 2010a).

These results demonstrate how the conflict adaptation effect is modulated by reward. This modulation of the congruency effect after reward seems to be primarily driven by a modulation of the congruent trials (cf. Akcay & Hazeltine, 2007; Fernandez-Duque & Knight, 2008; Ullsperger, Bylsma, & Botvinick, 2005). Compared to after incongruent no-reward trials, congruent trials are processed slower after incongruent rewarded trials, t(20) = 2.3, $p < .05$, suggesting a more cautious response strategy after conflict. Similarly, congruent trials are processed faster after congruent rewarded trials, compared to after congruent no-reward trials, t(20) = 3.0, $p < .01$. In explaining this pattern of the conflict adaptation effect, where conflict trials do not seem to modulate subsequent conflict trials, Schlaghecken and Martini (2012) recently stressed the importance of context, rather than conflict. The authors suggest that both congruent and incongruent trials modulate behavior and thereby nuance current theories of cognitive control that focus on the role of incongruent (conflicting) trials. Nevertheless, the relative cost of incongruent trials (as compared to congruent trials) was significantly reduced after conflict, indicating increased task focus. Importantly, if the enhancement of the conflict adaptation effect after reward is indeed the result of increased task focus, we can expect a similar modulation of the conflict-modulated task switch cost.

EXPERIMENT 2

Here, we tested whether reward modulates the adaptation to conflict in task-switch costs. We used a task-switching design with an arrow flanker task and a Simon task (Simon, 1969), with reward signals. The Simon effect is the observation that responses are faster when stimulus and response locations correspond, despite the stimulus location being irrelevant (Simon, 1969). Contrary to the original bivalent-stimulus designs by Goschke (2000) and Brown et al. (2007), where conflict results from cross-task interference, we used two independent conflict tasks where conflict originates from competing responses within a task. To our knowledge, a conflict-modulated task switch cost has not been demonstrated in such a design, but it is predicted by cognitive control theories (Verguts & Notebaert, 2009). Our control condition, without reward manipulation, can therefore be considered as a test of this prediction.

Method

Participants

Forty-four students took part in exchange for credits (range = 17-22 years, 42 female, 37 right-handed, 20 per condition).

Stimuli

For the Simon task the stimuli consisted of the character ‘X’ in blue or red, presented on the left or right side of the screen. In the flanker task, the stimuli were centrally presented arrows pointing left or right, flanked by congruent or incongruent arrows on each side.

Procedure

Participants performed a flanker or Simon task, depending on the presented stimulus. In the flanker task, participants pressed right (left) when the middle arrow pointed to the right (left). In the Simon task, subjects pressed right (left) when the letter ‘X’ was blue (red). The assignment of stimulus colour to response was counterbalanced across participants. 25% of the trials were reward trials, randomized for tasks and congruency conditions separately. The same reward schedule, block/trial procedure, apparatus and control condition were used as in Experiment 1. The maximum RT was set to 750 milliseconds.

Questionnaires

All 22 participants from the reward condition filled in the BIS/BAS-Scales, immediately after the experiment.

Results and Discussion

In each condition (reward and neutral feedback), one participant was excluded because of an accuracy two standard deviations below the group mean (group averages: *M*=0.90; *SD*=0.05 and *M*=0.88; *SD*=0.11). Trials following an error and the first trial of each block were removed. For the RT analyses, errors were also excluded. From the remaining trials, RT outliers (±2*SD*) were removed (3.7%). We carried out an ANOVA with three within-subject factors (task sequence, previous-congruency and previous-feedback) and the between-subjects factor feedback condition on RTs and error rates.

There was a significant task-switch cost, *F*(1,40)=342.393, *p*<.001, which interacted with previous-congruency, *F*(1,40)=7.575, *p*<.01, indicating a significant conflict-modulated task switch cost. A four-way interaction between feedback condition, task sequence, previous-congruency, and previous-feedback hinted at different effects of the "feedback" stimuli, *F*(1,40)=3.000, *p*=.09. Crucially, in the experimental condition, there was a significant three-way interaction between task sequence, previous-congruency, and previous-feedback, *F*(1,20)=5.704, *p*<.05. As can be seen in Figure 2a, the modulation of the task switch cost is only observed after reward trials, *F*(1,20)=4.819, *p*<.05 (subtracting the task-switch cost after congruent from the task-switch cost after incongruent trials: 12ms), but not after no-reward trials (-2ms). There was neither a main effect of previous-reward, nor a task-switch cost by previous-reward interaction (both *p*>.1). Similar to Experiment 1, there was only a conflict-modulated task switch cost after reward. In the control condition, a significant modulation of the task switch cost was observed, *F*(1,20)=4.630, *p*<.05, which was not modulated by the irrelevant stimulus presentation (*F*(1,20)<1, Figure 2b, 8ms after “@” and 8ms after blank screen).

Error rates only showed a significant task-switch cost *F*(1,40)=53.526, *p*<.001.

As predicted, the questionnaires revealed a positive correlation between the difference in the conflict-modulated task switch cost (modulation of the task switch cost after reward minus after no-reward) and the BAS-Reward-Responsiveness subscale (r=.617, p<.005, Spearman's ρ=.581, p<.01, Figure 2c). The difference in the task switch cost modulations did not correlate with other scales (all *p*>.1).

As in Experiment 1, to rule out the effects of stimulus or response repetitions (e.g., Hommel, Proctor, & Vu, 2004), we reanalyzed our data from the reward condition by means of multiple regression. Along with our previously reported variables of interest, we added two binary (0 or 1) bottom-up factors (see Notebaert & Verguts, 2007), to our multiple regression analysis with reaction time as the dependent variable: The first factor was target repetition, and the second factor response repetition. Moreover, we also controlled for the interactions between previous reward and each of those factors. Similar to Experiment 1, the analyses show that our main interaction of interest (task sequence, previous-congruency, and previous-feedback) can still be observed, t(20)=2.366, *p*<.05, after controlling for the significant main effects of target repetition and response repetition (both *p*<.001).

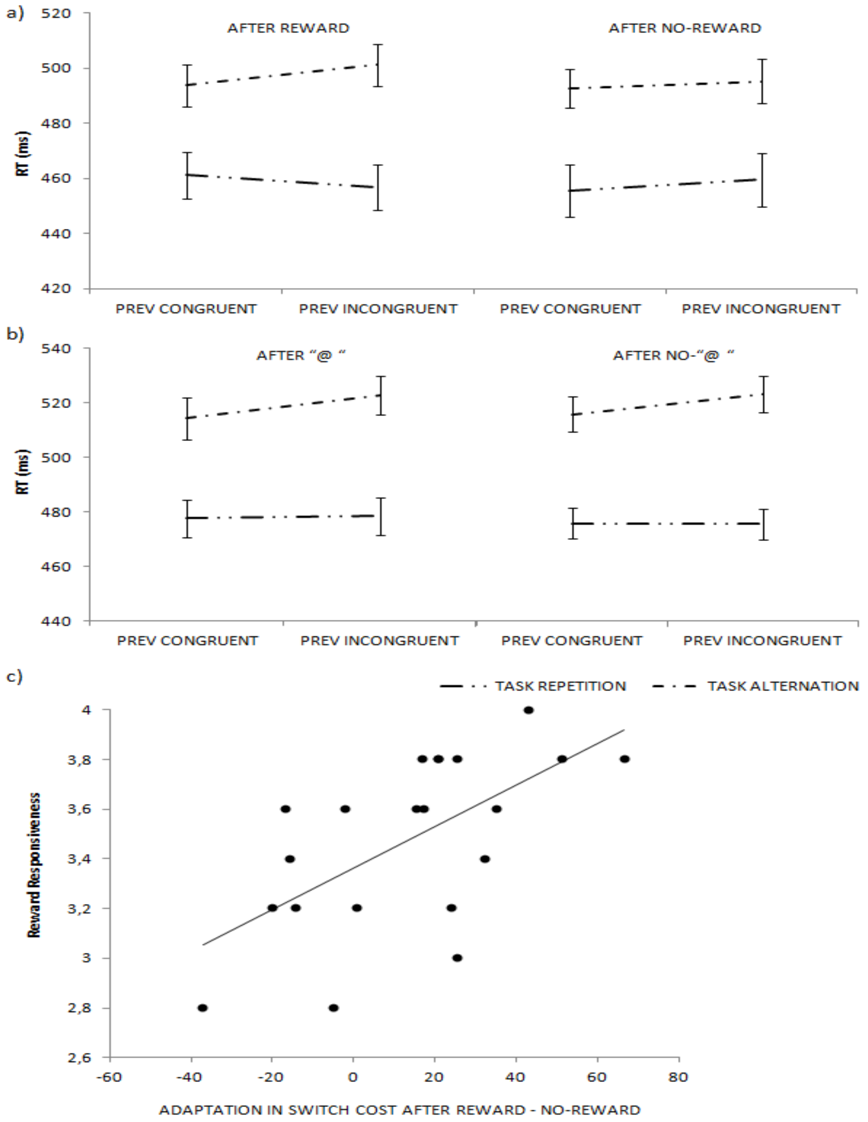

Figure 2. Response times for Experiment 2, reward feedback condition **(a)**; and neutral feedback condition **(b)**. The figure demonstrates how reward modulated the conflict-modulated task switch cost. Below, the scatter plot shows the correlation between individual scores on the BAS-Reward Responsiveness scale and the difference scores for the modulations of the tasks switch cost **(c)**. The error bars are ± 1 standard error.

GENERAL DISCUSSION

The experiments demonstrated how cognitive adaptations after incongruent trials can be modulated by reward. More specifically, reward feedback modulated conflict adaptation (measured by congruency effect and task-switch cost in Experiments 1 and 2, respectively), and these reward modulations were subject to individual differences in reward responsiveness, as measured by the BAS-Reward-Responsiveness subscale.

The current study extends earlier findings suggesting that rewarding events reinforce binding (Colzato et al., 2007; Waszak & Pholulamdeth, 2009), but also a more generally growing literature pointing to the influential role of reward in cognitive control. For instance, by rewarding two colours in a four-choice Stroop task, Krebs, Boehler, and Woldorff (2010) observed that reward strengthens specific stimulus-response bindings, thereby reducing the congruency effect for rewarded stimuli only. Similarly, these results add to the findings of Stürmer, Nigbur, Schacht, and Sommer (2011) which showed an enhanced conflict adaptation effect in a Simon task after reward, when rewarding the top fastest responses. On a perceptual level, Hickey, Chelazzi, and Theeuwes (2010a) demonstrated how processing reward-associated visual features was facilitated, even when resulting in suboptimal performance. Furthermore, they demonstrated how these effects of reward are limited to task-relevant target selection, but not distracter suppression (Hickey, Chelazzi, & Theeuwes, 2011). Interestingly, the latter two studies also demonstrated how reward acts as a context changer. In their studies, normally observed priming effects were only observed after high reward, not after low reward. Similarly, we only observed conflict adaptation after reward. These results demonstrate that no-reward trials are not just a neutral and constant baseline. Instead, by introducing reward signals, we gave both reward and no-reward trials an informative value. Possibly, the absence of reward may have devaluated the learning value of the conflict signal (see below). Alternatively, our results could be interpreted in terms of punishment in that participants could feel punished after no-reward trials. However, since participants were truthfully informed on the reward schedule and knew to expect no-reward trials on 75 percent of the trials, we believe that they did not perceive no-reward trials as punishing. Furthermore, our correlation with BAS Reward Responsiveness (and no correlation with BIS) suggests that a reward, rather than punishment, modulation explains our current effects.

The individual differences in BAS Reward Responsiveness predicted the modulations of reward on adaptations to conflict in both experiments. This is consistent with earlier reports demonstrating the important role of BAS Reward Responsiveness (Boksem, Tops, Wester, Meijman, & Lorist, 2006, De Pascalis, Varriale, & Antuono, 2010), and BAS overall (Amodio, Master, Yee, & Taylor, 2008), in explaining individual differences in cognitive control. However, it must be noted that earlier studies looking at the after-effects of reward signals in cognitive control often also found correlations with BAS Drive, rather than BAS Reward Responsiveness (Hickey, Chelazzi, & Theeuwes, 2010b, Van Steenbergen, Band, & Hommel, 2009). Similarly, our modulation in Experiment 1, but not Experiment 2, correlated with BAS Drive. Yet, it has been suggested, that BAS Drive and BAS Reward Responsiveness may as well tap a similar construct (Franken & Muris, 2006; Zelenski & Larsen, 1999), both measuring reward sensitivity. Hence, differential modulation of the BAS Drive and BAS Reward Responsiveness subscales has to be treated with caution.

We believe that our findings can be parsimoniously explained by associative models of cognitive control. Literature suggests that reward signals modulate binding processes and the theoretical framework of Verguts and Notebaert (2008, 2009) describes how adaptations after conflict can be understood in terms of adaptation by binding. Therefore, we reasoned that, by strengthening task-relevant associations, rewards should modulate the effects of cognitive conflicts. We demonstrated this in two different adaptations to conflict. Importantly, to our knowledge, our conflict-modulated task-switch cost (Goschke, 2000) is the first one observed in a task-switching study with two independent conflict tasks (Experiment 2), as predicted by the model of Verguts and Notebaert (2009). Lastly, Verguts and Notebaert (2009) also suggested that the strengthening of associations after conflict is mainly triggered by conflict-induced arousal. This idea, that arousal helps strengthening associations, is consistent with our finding that people who feel more energized or aroused after reward (as measured by BAS Reward Responsiveness) show a greater modulation of their adaptation to conflict.

Alternatively, the feature integration account (Hommel, Proctor, & Vu, 2004) explains these sequential effects in terms of stimulus-response repetitions. In this view, the observed modulation of these sequential effects by reward could be due to the enhancement of stimulus-response associations by reward. The adaptation-by-binding account (Verguts & Notebaert, 2009) relates to this theoretical framework, in that both use binding to explain these cognitive adaptations. However, the adaptation-by-binding model holds that conflict enhances all active task-relevant associations (including, but not only, repeating stimulus-response associations). Therefore, by means of multiple regression (Notebaert & Verguts, 2007), we demonstrated how reward modulations of adaptations to conflict can still be observed after controlling for feature integration effects and their interactions with reward (see Results). This indicates that the effect of reward goes beyond strengthening stimulus-response associations and reflects the modulation of conflict-based adaptations.

The influential conflict monitoring theory of Botvinick et al. (2001) explains these adaptations to conflict by enhanced task attention after conflict. This model implements cognitive control on a different level than the adaptation-by-binding account (see Braem, Verguts, & Notebaert, 2011). Yet, the conflict monitoring theory could also explain our main findings, albeit with the additional assumption that reward enhances top-down attention (e.g., Della Libera & Chelazzi, 2006; Locke & Braver, 2008).

However, it is important to note that the conflict monitoring theory has led to opposite predictions as well. Van Steenbergen, Band, and Hommel (2009) hypothesized, on the basis of conflict monitoring, that people relax their control system when receiving reward. The authors suggested that, if the aversive quality of conflict (Botvinick, 2007) signals the need for adjustment, it should be possible to counteract control operations when presenting positive reward signals. This was tested by combining a standard flanker task with punishment and reward signals, similar to our Experiment 1. Interestingly, however, van Steenbergen et al. (2009) observed a conflict-modulated congruency effect in a flanker task after neutral and punishment trials (neutral and sad faces, respectively), but not after rewarded trials (happy face). However, rewards were not contingent on the response accuracy, whereas in our study, reward signals only followed correct responses and participants were explicitly informed about this. Therefore, van Steenbergen et al. may have observed the modulating effects of the more affective effects of reward, as induced by the faces, rather than the motivational effects of reward. This would be in line with the results of Dreisbach and Goschke (2004), who found increased distractibility following positive affect inducing pictures independent of response accuracy. We believe that the modulation of this conflict adaptation effect by short-term (van Steenbergen et al., 2009) or long-term (van Steenbergen, Band, & Hommel, 2010) affect inductions should be distinguished from the motivational aspect of reward. This relates to the neurobiological theory of Berridge and Robinson (2003), conceptualizing the different motivational, learning, and affective components of reward. In their view, our results could be a manifestation of the motivational and learning effects of reward, whereas the study of Van Steenbergen et al. (2009) demonstrated effects of the affective component of reward. The need for a differentiation between these effects of motivation and positive valence was also recently stressed in a review by Chiew & Braver (2011) and calls for further research.

When focusing on the affective value of reward, it might seem surprising that reward enhances the cognitive adjustments triggered by conflict. Cognitive conflict has been suggested to be aversive (Botvinick, 2007; Dreisbach & Fisher, 2012) or at best arousing (Verguts & Notebaert, 2009). However, when focusing on the motivational aspect, successfully responding to a more difficult task can be associated with increased intrinsic reinforcement signals (Satterthwaite et al., 2012). Hence, participants can find it more motivationally significant to complete an incongruent trial than a congruent trial. In this way, while conflict may be experienced as negative (Dreisbach & Fischer, 2012), conflict resolution can be perceived as positive. Consistently, a recent computational model demonstrates how correctly responding to incongruent trials can generate larger positive prediction errors (as compared to congruent trials) in anterior cingulate cortex (Silvetti, Seurinck, & Verguts, 2011).

Carrying this reasoning one step further, this motivating aspect of conflict resolution, rather than conflict itself, may be what steers typically observed cognitive adaptations. This intrinsic reward would then be what motivates a person to enhance the task-relevant associations that drove him/her to that response. In line with this, patients with Parkinson’s disease, who exhibit a reduced sensitivity to reward (Frank, Seeberger, & O’Reilly, 2004), typically do not show a conflict adaptation effect (e.g., Fielding, Georgiou-Karistianis, Bradshaw, Millist, & White, 2005; Praamstra & Flat, 2001). Possibly, patients with Parkinson’s disease are not susceptible to the motivating aspect of incongruent trials. In fact, this idea also fits our data: incongruent trials reduced the congruency effect (Experiment 1) and enhanced the task-switch cost (Experiment 2) only after reward. In our experiment, the external reward may have superseded the intrinsic reward signal, so that people no longer learn from conflict, in the absence of their hoped-for reward.

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CHAPTER 4

REWARD MODULATES CONTEXT-SENSITIVE COGNITIVE CONTROL[1]

Reward is thought to enhance cognitive control processes in various ways (e.g., Braem, Verguts, Roggeman, & Noteabaert, 2012; Krebs, Boehler, & Woldorff, 2010), but the impact of reward on the context-sensitivity of cognitive control (Verguts & Notebaert, 2008, 2009) remains unclear. Evidence from perception and attention studies suggests that good outcome acts to increase saliency for attended visual features, whereas sub-optimal outcome results in the devaluation of these features (e.g. Hickey, Chelazzi, & Theeuwes, 2010a). Here we investigated the possibility that this interplay between reward and contextual visual features can impact higher cognitive control processes, such as conflict monitoring. By combining a visual search paradigm with a letter flanker task we demonstrated that the congruency sequence effect is strong after high reward when irrelevant task features repeat, but also strong after low reward when those features alternate. These modulations of trial-to-trial adaptations to conflict are predicted by individual differences in reward responsiveness. The results suggest a role for reward in context-modulated cognitive control and are discussed in light of a win-stay / lose-shift strategy.

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[1] Braem, S., Hickey, C., Duthoo, W., & Notebaert, W. (under revision). Reward modulates context-sensitive cognitive control: A win-stay / lose-shift account..

INTRODUCTION

In order to achieve our goals we must monitor our environment and adapt to ever-changing contexts. Feedback regarding action outcomes is well known to play a role in guiding this type of cognitive control. In spite of this, there are relatively few direct investigations of the manner in which explicit reward feedback impacts cognitive control processes (e.g., Braem, Verguts, Roggeman, & Notebaert, 2012; Stürmer, Nigbur, Schacht, & Sommer, 2011; van Steenbergen, Band, & Hommel, 2009). Recent empirical evidence has demonstrated how trial-to-trial cognitive adaptations processes can be tied to specific stimulus- (Spapé & Hommel, 2008) or response- (Braem, Verguts, & Notebaert, 2011) features, arguing for the context-sensitivity of cognitive control (Blais, Robidoux, Risko, & Besner, 2007; Davelaar & Stevens, 2009; Verguts & Notebaert, 2008; 2009). In the present study, we investigated how contextual task features play a role in determining the impact of reward on cognitive control.

Generally, cognitive control is investigated through the use of conflicts tasks like the Eriksen flanker task (Eriksen & Eriksen, 1974), Stroop task (Stroop, 1935) or Simon task (Simon, 1969). In all these tasks, irrelevant, conflicting stimulus information impedes the processing of relevant stimulus information. For example, in a standard flanker task participants are required to respond as fast as possible to a centrally presented target, such as identifying a certain letter (e.g., press left when 'S', right when 'H'). Irrelevant flankers presented next to the central target impede task performance when they are incongruent, as when these letters are associated with an alternative response (e.g., 'HHSHH'), but facilitate task performance when congruent, as when they are the same letters as the central target (e.g., 'SSSSS'). Resulting differences in reaction time (RT) and accuracy are referred to as the congruency effect.

The congruency effect observed in the flanker task is typically found to be smaller after incongruent trials than after congruent trials (as first observed by Gratton, Coles & Donchin, 1992). This congruency sequence effect has been replicated in different congruency tasks (Kerns et al., 2004; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002) and offers an index of how people increase task focus in reaction to cognitive conflict. The congruency sequence effect appears to be context-specific, restricted to circumstances where perceptual context repeats between experimental trials. Spapé and Hommel (2008), for example, demonstrated how the congruency sequence effect could only be observed when the voice in which the stimulus was presented repeated between trials. In a similar vein, Braem, Verguts, and Notebaert (2011) found that the congruency sequence effect only occurs within response effectors (feet or hand), but not across. This is in line with recent associative models of cognitive control (Blais, Robidoux, Risko, & Besner, 2007; Davelaar & Stevens, 2009; Verguts & Notebaert, 2008; 2009) that stress the importance of modulating task associations after conflict. For example, Verguts and Notebaert (2008, 2009) proposed that cognitive conflict leads to arousal, which has the effect of binding active representations together. Task-relevant associations will be more strongly modified, resulting in a smaller congruency effect on the next trial. By explaining the congruency sequence effect in terms of strengthening specific stimulus-response associations (in contrast to, for example, enhancing overall task focus; Botvinick, Braver, Barch, Carter, & Cohen, 2001), this model provides a context-sensitive implementation of cognitive control. Inherent to this mechanism (i.e. strengthening and associating all active stimulus features and task representations after conflict), subsequent adaptations are predicted to be highly sensitive to what is active or salient at the time. Interestingly, given that reward is known to modulate the saliency or relative activation of stimulus features, we expect reward signals to play a major role in determining the context-specificity of cognitive control.

For over a century psychologists have been discussing and investigating the effects of reward on behaviour (Thorndike, 1911; Skinner, 1953; Schultz, 2002). Reward signals are widely thought to reinforce stimulus-response associations (i.e., the law of effect; Thorndike, 1911). Neurophysiological data suggest that this effect relies on dopaminergic signalling in the midbrain (Robbins & Everitt, 1996; Schultz, 2002; Kelley, 2004; Schultz, 2004). For example, reward has been found to stimulate the potentiation of connections between striatum and cortex in rats, with the strength of this physiological effect predicting the animal's subsequent ability to learn a new task (Reynolds, Hyland, & Wickens, 2001). Similar behavioural effects have been observed in humans, with reward - in the form of positive valence inducing pictures - increasing both short- (Colzato, van Wouwe, & Hommel, 2007) and long-term (Waszak & Pholulamdeth, 2009) stimulus-response associations.

In recent years reward has also become a focus for researchers investigating selective attention (Anderson et al., 2011a, 2011b, 2012; Anderson & Yantis, 2012; Della Libera & Chelazzi, 2006, 2009; Hickey & Peelen, under review; Hickey et al., 2010a, 2010b, 2011; Hickey & van Zoest, 2012; Raymond & O’Brien, 2009; Rutherford, O'Brien, & Raymond, 2010). For example, Hickey, Chelazzi, and Theeuwes (2010a) demonstrated that selective attention is automatically biased towards stimuli with reward-associated visual features. These authors had human participants search for a uniquely-shaped target presented among a number of homogenous distractors. Response was based on the orientation of a small line presented within the target shape. In some trials, all the shapes were of the same colour, but more often one of the distractor shapes had a different colour. This type of irrelevant colour singleton is known to draw attention during visual search for the unique shape (e.g., Theeuwes, 1991; Hickey, McDonald, & Theeuwes, 2006). The colours of the target could vary from trial to trial such that the distractor could be red, with all other stimuli including the target green, or vice versa. Therefore, the colours could either alternate or repeat between trials, with the colour of the target (distractor) becoming that of the distractor (target), or could remain the same. Participants randomly received either high- or low-magnitude monetary reward after each correct trial. Results showed that when high reward was received, attention was biased towards stimuli with the same colour in the next trial. Even though colour was task irrelevant, task performance thus improved when target colour repeated, but suffered when target colour alternated and the salient distractor acquired the reinforced colour.

Interestingly, in the study of Hickey et al. (2010a) low reward was found to create the reverse pattern of high reward: response was slow when the colours of the target and salient distractor were repeated after low reward, but performance improved when these colours swapped. This pattern suggests that low reward resulted in a relative deactivation of the attentional template for the target in that trial, and a corresponding increase in perceptual sensitivity for features characterizing the distractor. As a result, target processing was facilitated in the next trial when the target was characterized by visual features that had defined the distractor in the preceding trial. Similarly, in a study of the long-term effects of reward learning, Della Libera & Chelazzi (2009) demonstrated that distractors that have been associated with low reward are easier to detect when they reappear as targets than are target items that have been associated with low reward.

We have demonstrated how adaptations to conflict can be determined by task (ir)relevant contextual features, and this opens the possibility that reward modulations of the saliency of such features might determine the impact of reward signals on cognitive control. In order to investigate this impact of reward on a context-sensitive conflict task we integrated a visual search paradigm with a flanker task paradigm. More specifically, we used the visual search paradigm of Hickey et al. (2010a, 2010b, 2011), in which participants look for an object with a unique shape and respond based on the orientation of a small line segment in this object. In our modification of this paradigm each item in the visual search array contained a small flanker sequence and response was based on the identity of the central letter in the sequence presented within the uniquely-shaped target. This design allowed us to investigate the influence of reward signals and contextual features on the congruency sequence effect. The combined notion of the context sensitivity of adaptations after conflict (i.e., adaptation by binding, Verguts & Notebaert, 2008; 2009) and the role of reward in modulating contextual features (Hickey et al., 2010a, 2010b, 2011) motivates four experimental predictions in this hybrid task: the congruency sequence effect will increase when (a) contextual features (i.e., target and distractor colours) repeat after high reward and (b) when these alternate after low reward, but will decrease when (c) context alternates after high reward and (d) when context is repeated after low reward. Moreover, we expect that individual variability in the effect of reward will be related to trait reward sensitivity, as has been demonstrated in visual search (Beaver et al., 2006; Hickey, Chelazzi, & Theeuwes, 2010b; Hickey & Peelen, under review) and cognitive control tasks (Braem et al., 2012; van Steenbergen et al., 2009). Therefore, participants completed a personality index - the BIS/BAS scale (Carver & White, 1994) - after having completed the experiment. Experiment 1 was designed to determine if the known context sensitivity of conflict adaptation could be detected in a visual search paradigm in the absence of a reward manipulation. Experiment 2 and 3 employed much the same paradigm, but included a variable reward feedback that was provided at the end of each trial.

EXPERIMENT 1

Method

Participants

Fifteen students (range = 18-23 years, 10 female, all right-handed) took part in return for course credits.

Stimuli and procedure

The trial procedure is visualized in Figure 1. The visual search arrays contained six object outlines (line thickness of 0.3° visual angle), each presented equidistant (9.1°) from a central fixation point and from each other. Objects could be diamonds (4.2° x 4.2°) or circles (3.4° diameter), with each display containing only one uniquely shaped item. This shape singleton could be a diamond with all other stimuli circles or vice versa. In 80% of trials, one of the homogenously shaped non-target items was of unique colour, either red with all other objects green or vice versa.

Each of the six object outlines contained a sequence of five characters aligned horizontally. Participants responded based on the central character: half of participants pressed the left response button when this letter was an ‘S’ and the right button it was an ‘H’ with the response map swapped for the remainder. Non-target characters could have the same identity, rendering the target flanker congruent (e.g., SSSSS), or could have the alternative identity, rendering the target incongruent (e.g., HHSHH). Per block, target shape (circle or diamond), target colour (green or red), flanker task congruency (congruent or incongruent), and distractor presence (80 % present and 20 % absent), were randomized in a balanced manner. Per congruency condition, half of the target shapes were in green, the other half in blue.

The onset of the visual search array was preceded by a fixation cross for a random duration of 400–1400 milliseconds. Responses were registered with a standard response box. Errors were indicated with the Dutch word 'fout' (mistake) in black text for 500 ms. No feedback was provided for correct responses but the fixation cross sustained for an additional 500 ms in these trials.

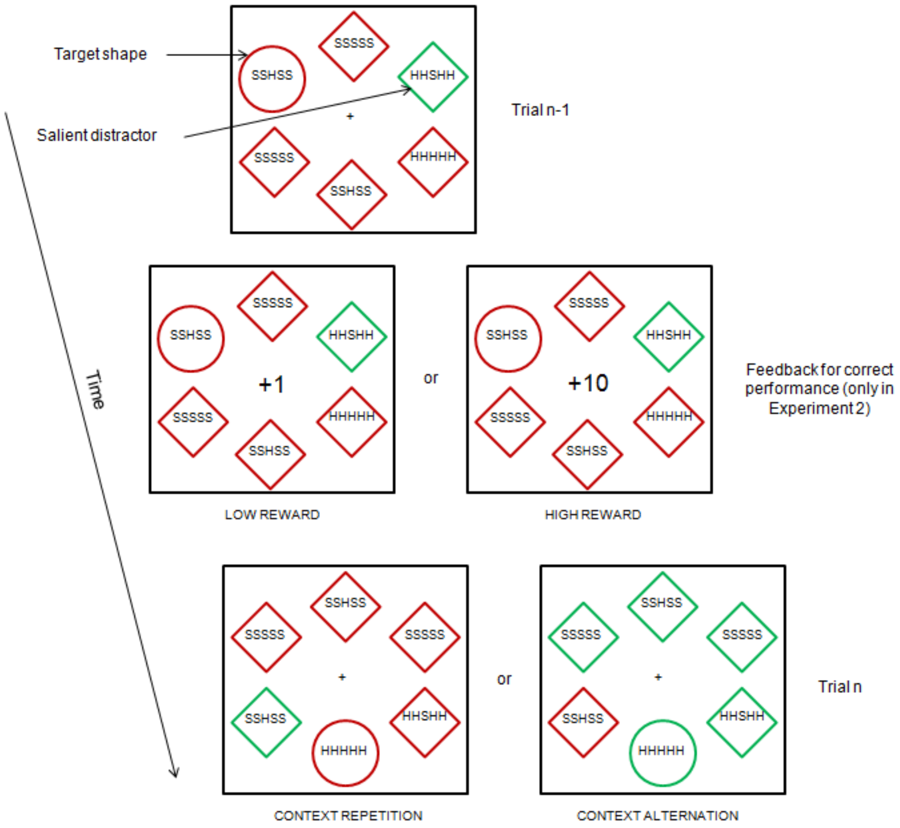

Figure 1. General paradigm and trial procedure for Experiment 1 and 2. The target shape and salient distractor are denoted. Participants had to identify the unique (target) shape, while ignoring the salient distractor, and respond to the central letter in the target shape (Flanker task). In Experiment 2, correct performance was rewarded with either 1 or 10 points. There was no reward schedule in Experiment 1.

Stimuli were presented on a CRT monitor located 60 cm away from the eyes using Tscope software (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 2006). Participants completed 14 blocks of 40 trials for a total of 560 trials, which took approximately 40 minutes. A self-paced break was provided between blocks. All participants were given detailed instructions regarding the experimental task.

Results

Mean accuracy was high (M = 96%, SD = 0.04). Inter-trial analyses are based on correct colour-distractor-present trials where the trial was preceded by a correct colour-distractor-present trial in the same block. Of these trials, 4.6 % were RT outliers (± 2 SD) and were discarded from further analysis. RT and accuracy results were statistically assessed in repeated-measures analyses of variance (rANOVA) with within-subject factors for flanker congruency (congruent vs. incongruent), previous flanker congruency (previous congruent vs. previous incongruent), colour sequence (colour repetition vs. colour alternation), and shape sequence (shape repetition vs. shape alternation).

Overall, there was a significant flanker congruency effect, $F(1, 14) = 27.114$, $p < .001$, which did not interact with previous flanker congruency, $F(1, 14) = 1$, $p > .1$. A significant effect of shape sequence was also revealed, $F(1, 14) = 17.141$, $p < .01$, driven by faster reaction times on shape repetitions relative to shape alternations. The three-way interaction between colour sequence, congruency and previous trial congruency was significant, $F(1, 14) = 5.433$, $p < 0.05$. As depicted in Figure 2a, this indicates that the congruency sequence effect was only observed for colour repetitions, $t(14) = 2.432$, $p < 0.05$, with no congruency sequence effect observed for colour alternations $t(14) < 1$, *ns*. In addition, we observed a significant interaction between congruency and shape sequence ($F(1, 14) = 5.906$, $p < .05$), indicating a reduced congruency effect (60 ms) after shape alternations relative to shape repetitions (108 ms). No other interactions reached significance (all $p > 0.1$).

The error rates analyses only showed a marginally significant main effect of congruency, $F(1, 15) = 3.182$, $p = 0.096$, and an interaction between congruency and shape sequence, $F(1, 15) = 4.591$, $p = 0.05$, indicating a congruency effect on shape repetitions (2.8%), but not on shape alternations (-0.4%). No other interactions reached significance (all $p > 0.1$).

Discussion

This first experiment is in line with earlier observations suggesting that the congruency sequence effect is sensitive to changes of stimuli characteristics or response modality (Braem et al., 2011; Spapé & Hommel, 2008). Here, we demonstrate that this effect can also be bound to the context (surrounding colour) in which task stimuli are presented, and suggest that context repetitions in visual search facilitate not only target detection and localization, but also the operation of subsequent mechanisms involved in conflict adaptation.

We conducted a second experiment in order to determine the role of reward in modulating this effect of context on the congruency sequence effect . Experiment 2 relied on the same general paradigm as employed in Experiment 1, but with the addition of high and low reward feedback at the end of each trial.

EXPERIMENT 2

Method

Participants

Fourteen students took part for credit (range = 18-19 years, 12 female, 2 left-handed).

Stimuli and procedure

The trial procedure was similar to Experiment 1 with the following modifications (see Figure 1): the shape singleton was always a circle and distractor-shapes were always diamonds, and correct responses to the search target were immediately followed by the replacement of the central fixation cross with reward feedback in black text, either ‘+10’, denoting the receipt of 10 points, or ‘+1’, denoting the receipt of 1 point. Per block, reward feedback (low or high reward), target colour (green or red), flanker task congruency (congruent or incongruent), and distractor presence (80 % present and 20 % absent), were randomized in a balanced manner. The search array and flanker stimuli remained onscreen during the 1000 ms presentation of feedback. Incorrect responses resulted in the removal of 10 points, denoted by ‘-10’, and for every 10 participants that completed the experiment the top-scorer received a 25€ store coupon.

Questionnaires

All 14 participants completed a Dutch version (Franken, Muris, & Rassin, 2005) of the BIS/BAS scale (Carver & White, 1994) immediately after the experiment. In the BIS/BAS scale participants rate their agreement with a series of 20 statements on a 4-point scale (eg. ‘I go out of my way to get things I want.’).

Results

As in Experiment 1, mean accuracy was high (M = 98%, SD = 0.02), inter-trial analyses are based on correct colour-distractor-present trials where the trial was preceded by a correct colour-distractor-present trial in the same block, and RT outliers were discarded from analysis (± 2 SD; 4.4 %). RT and accuracy results were statistically assessed in a rANOVA with within-subject factors for flanker congruency (congruent vs. incongruent), previous flanker congruency (previous congruent vs. previous incongruent), colour sequence (repetition or alternation), and previous reward (high vs. low magnitude). Analysis of RT revealed a significant congruency effect, $F(1, 13) = 101.417$, $p < .001$, which interacted with previous congruency, $F(1, 13) = 15.155$, $p < .01$, indicating an overall congruency sequence effect. Also, there was a marginally significant effect of colour sequence, $F(1, 13) = 4.449$, $p = .055$, indicating shorter reaction times on colour repetitions relative to colour alternations. We did not replicate the interaction between colour sequence and previous feedback, as found by Hickey et al. (2010a, 2010b, 2011), $F(1, 13) = 1.549$, $p > .1$. However, we believe that, due to the more complex double task procedure (visual search and conflict task) in our design, this originally observed two-way interaction may have been overridden by the variation induced by the flanker task. Critically, the interaction between congruency, previous congruency, previous feedback and colour sequence was significant, $F(1, 13) = 4.792$, $p < .05$, demonstrating the context-dependent impact of reward on the congruency sequence effect. No other interactions reached significance (all $p > 0.1$).

As depicted in Figure 2b, the four-way interaction in RT is reflected in the presence of a congruency effect (as calculated by subtracting the congruency effect after incongruent trials from the congruency effect after congruent trials) after high reward when context (target and distractor colour) repeated (102 ms, $t(1, 13) = 3.070$, $p < .01$) and after low reward when the context alternated (94 ms, $t(1, 13) = 3.171$, $p < .01$) on the one hand, and the nonsignificance of a congruency sequence effect after high reward when the context alternated (38 ms, t(1, 13) = 1.463, p > .1) and after low reward when the context repeated (26 ms, t(1, 13) < 1, n.s.) on the other.

Analysis of error rates garnered no significant results (all p > 0.1).

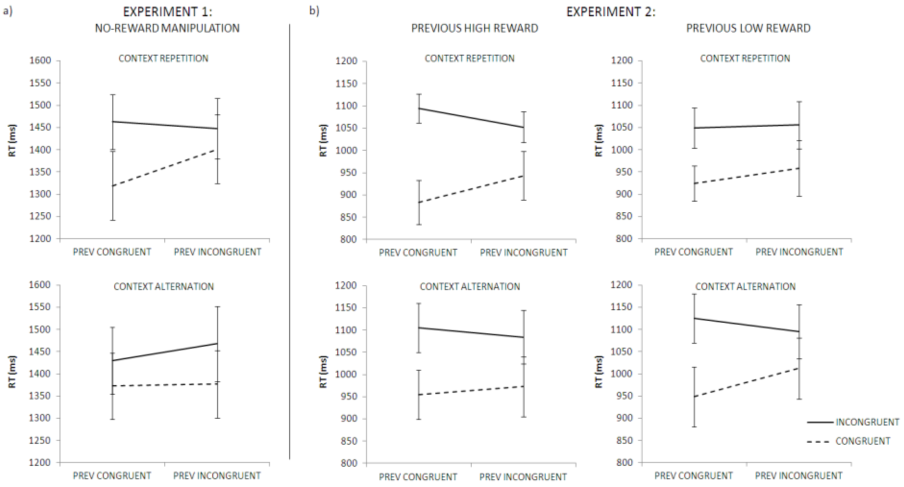

Figure 2. Depicted are the reaction times for Experiment 1 **(a)** and Experiment 2 **(b).** Dotted lines indicate congruent trials and full lines indicate incongruent trials. The results demonstrate how conflict adaptation is normally observed for context repetitions only (Experiment 1). When implementing a reward schedule, conflict adaptation is observed for context repetitions after high reward, but on context alternations after low reward (Experiment 2). The error bars are ± 1 standard error.

Analysis of the distractor effect: a manipulation check.

The analysis described above (in Experiment 1 and 2) are based on trials where the colour-distractor was present, and extant results suggest that this colour-distractor will draw attention during search (e.g. Theeuwes, 1991; Hickey, McDonald & Theeuwes, 2006). To verify this effect in the current dataset we conducted an additional analysis contrasting colour-distractor present and colour-distractor absent conditions. This took the form of a rANOVA with a within-subject factor for colour-distractor presence (present vs. absent) and between-subject factor for experiment (Experiment 1 vs. 2). This revealed a main effect of experiment, $F(1, 27) = 17.014$, $p < .001$, a main effect of colour-distractor presence, $F(1, 27) = 71.480$, $p < .001$, and a significant interaction between both factors, $F(1, 27) = 19.914$, $p < .001$. Participants were thus slower to respond in colour-distractor-present trials but this effect was reduced in Experiment 2 (130 ms vs. 40 ms), presumably reflecting the motivational impact of the possibility of explicit reward. Error rates indicated a similar trend but did not reach significance (all *p*'s > .1).

Discussion

In this second experiment, we investigated the role of reward in modulating the effect of context on the congruency sequence effect. We used the paradigm used in Experiment 1 and added low and high reward at the end of each trial. The results demonstrate how the congruency sequence effect is enhanced after high reward on context repetitions and after low reward on context alternations, but diminished following high reward on context alternations and after low reward on context repetitions. The results are in line with our predictions on reward modulations of context-sensitive cognitive control.

However, some aspects of our design could have coloured our results. Specifically, our design did not allow us to detect false positives. That is, flanker task stimuli were randomly presented in the non-target shapes. Whenever a participant responded to the flanker target in the colour-distractor shape, and this flanker target happened to be the same as in the target shape, the response was (wrongfully) coded as a correct response. The error rate in Experiment 1 and 2 was very low, rendering the idea that false-positives would shape our effects rather unlikely. However, to ensure false-positives would be excluded from our RT analyses, we employed a flanker task with four, as opposed to two, response options in a third experiment, Experiment 3. This way, we could program that neither the flankers, nor the target, where the same in the colour-distractor and target shape. Secondly, the number of data points per condition, after excluding previous and current no-colour-distractor trials, was relatively low in Experiment 2 (mean = 20, ranging from 9 to 35). Therefore, having established that a colour singleton distracts attention in our (see manipulation check in Results section) as well as previous studies (eg. Theeuwes, 1991; Hickey, McDonald & Theeuwes, 2006), we excluded all no-distractor trials from the design of Experiment 3 (each trial had a unique colour distractor shape). Furthermore, we added two more blocks to the experimental procedure. This way, Experiment 3 ensured a potential average of 39 trials per condition, as opposed to 21.8 trials in Experiment 2 (not taking into account previous and current error trials). Lastly, Experiment 3 is also of theoretical relevance. By employing a four-option response mapping, we can take into account the impact of feature integration effects (Hommel, Proctor, & Vu, 2004) and how these may, or may not, mediate the effect of reward on context-sensitive cognitive control.

EXPERIMENT 3

Method

Participants

Eighteen students took part for credit (range = 18-21 years, 15 female, 1 left-handed).

Stimuli and procedure

The trial procedure was similar to Experiment 2 with the following modifications. All trials had a uniquely coloured distractor, excluding all no-distractor trials by design. As in the previous two experiments, each of the six object outlines contained a sequence of five characters aligned horizontally and participants responded based on the central character. However, we employed a number, instead of letter, flanker task. All participants were required to press the D-key on the keyboard when the central target was number 1, the F-key when number 2, the J-key when number 3, and the K-key when number 4. This stimulus to response assignment (left to right, 1 to 4) was not counterbalanced across participants, because the order of this response mapping ensured the most efficient task performance (reducing the additional RT cost). Non-target characters could have the same identity, rendering the target flanker congruent (e.g., 11111), or could have an alternative identity, rendering the target incongruent (e.g., 44144). To guarantee a balanced number target-flanker combinations per congruency condition (see Mordkoff, 2012), we used a fixed selection of four incongruent trial types. Specifically, on incongruent trials target 1 was always flanked by 4 (i.e., 44144), 2 by 3, 3 by 1, and 4 by 2. The randomisation, trial procedure, and reward schedule was the same as in Experiment 2, but participants completed sixteen, instead of fourteen, blocks of 40 trials for a total of 640 trials, which took approximately 45 minutes.

Questionnaires

Similar to Experiment 2, all 18 participants completed a Dutch version (Franken, Muris, & Rassin, 2005) of the BIS/BAS scale (Carver & White, 1994) immediately after the experiment.

Results

Again, mean accuracy was high (M = 98%, SD = 0.01). Previous and current error trials, and first trials of each block were excluded from analysis, where after RT outliers were discarded from analysis (± 2 SD; 3.9 %). RT and accuracy results were statistically assessed in a rANOVA with within-subject factors for flanker congruency (congruent vs. incongruent), previous flanker congruency (previous congruent vs. previous incongruent), colour sequence (repetition or alternation), and previous reward (high vs. low magnitude). Analysis of RT revealed a significant congruency effect, $F(1, 17) = 207.624$, $p < .001$, which interacted with previous congruency, $F(1, 17) = 11.844$, $p < .01$, indicating an overall congruency sequence effect. Also, there was a significant effect of colour sequence, $F(1, 17) = 16.938$, $p < .01$, indicating shorter reaction times on colour repetitions relative to colour alternations. Critically, the interaction between congruency, previous congruency, previous feedback and colour sequence was significant, $F(1, 17) = 9.746$, $p < .01$, demonstrating a context-dependent impact of reward on conflict adaptation. No other interactions reached significance (all $p > 0.1$).

As depicted in Figure 3, the four-way interaction in RT is reflected in the presence of a congruency sequence effect after high reward when context (target and distractor colour) repeated (65 ms, $t(1, 17) = 3.035$, $p < .01$) and after low reward when the context alternated (36 ms, $t(1, 17) = 2.577$, $p < .05$) on the one hand, and the nonsignificance of a congruency sequence effect after high reward when the context alternated (-32 ms, t(1,

17) = -1.232, *p* > .1) and after low reward when the context repeated (35 ms, *t*(1, 17) = 1.331, *p* > .1) on the other.

Analysis of error rates garnered no significant results (all p > 0.1).

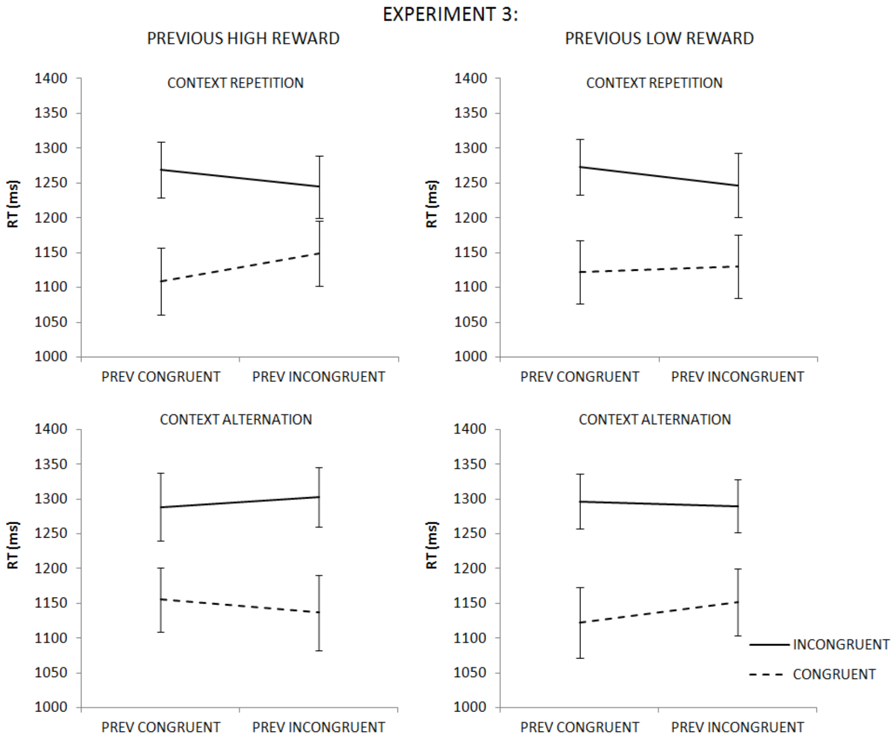

Figure 3. Depicted are the reaction times for Experiment 3. Dotted lines indicate congruent trials and full lines indicate incongruent trials. The congruency sequence effect only reached significance on context repetitions after high reward, and on context alternations after low reward. The error bars are ± 1 standard error.

In Experiment 3, we worked with four, instead of two (as in Experiment 2), response options. This allowed us to rule out effects of feature repetition and/or integration effects (e.g., Hommel, Proctor, & Vu, 2004) in explaining our reward modulation of contex-sensitive congruency sequence effects. Therefore, we reanalyzed our data by means of multiple regression (Braem et al., 2012; Notebaert & Verguts, 2007). To account for between-subjects variance, a multiple regression analysis is performed for each participant separately. Subsequently, the average of each coefficient across participants is tested with a one-sample t test (Lorch & Myers, 1990). This way, we can test if our crucial interaction between previous reward, context-sequence, previous congruency, and congruency (in the reward condition), remains after controlling for feature repetition and/or integration effects. Along with our previously reported variables of interest, we added five binary (0 or 1) bottom-up factors (see Notebaert & Verguts, 2007), to our multiple regression analysis with reaction time as the dependent variable. The first factor was the repetition of the target, and the second repetition of the flanker. The third factor, called feature integration, codes for complete repetitions and alternations (1) versus partial repetitions (0). The last two factors were respectively negative priming (distractor - becomes - target repetition) and target - becomes - distractor repetition. On top of those factors, we also chose to control for the interactions between previous reward, congruency sequence, and each of those factors. The analyses show that our main interaction of interest, between previous reward, context sequence, previous congruency and congruency, can still be observed, $t(17) = 2.330$, $p < .05$. This, after controlling for all the effects of feature repetition and their interaction with previous reward. The main effects of feature integration, target repetition, and flanker repetition, all reached significance (all $p < .01$), and negative priming showed a marginally significant effect, $t(17) = 2.006$, $p = .061$. There were no significant interactions between feature integration, or repetition effects, and previous-reward by congruency sequence (all $p > .1$).

Correlation analyses across Experiment 2 and 3

For these analyses, we took a measure of each congruency sequence effect separately (by subtracting the congruency effect after incongruent trials from the congruency effect after congruent trials, for each context sequence and previous reward condition separately). Next, the condition-specific congruency sequence effects were standardized per condition and per experiment. This allowed us to evaluate the impact of BIS/BAS scales on these respective congruency sequence effects across experiments, without contaminating the analyses with potential overall differences between Experiment 2 and 3. All correlations were evaluated by using fisher transformed rank-ordered Spearman's rho analyses, to ensure that correlations were not driven by outliers. As predicted, the questionnaires revealed a positive correlation between the congruency sequence effect following high reward on context repetitions and the BAS reward responsiveness subscale (Spearman’s rho, $\rho = .392$, $t(30) = 2.340$, $p < .05$) and a negative correlation between the BAS reward responsiveness subscale and the congruency sequence effect following low reward on context repetitions (Spearman’s rho, $\rho = .392$, $t(30) = 2.340$, $p < .05$), but not with the congruency sequence effects context alternations (both *p's* > .3). Both correlations are consistent with those observed in Braem et al. (2012) and van Steenbergen et al. (2009). No corresponding correlations with other BIS/BAS subscales were detected (all *p*'s > .1).

GENERAL DISCUSSION

In this study we have demonstrated an impact of reward feedback on the congruency sequence effect that is dependent on visual context. We had participants complete a hybrid conflict / visual search task in which a response-relevant flanker sequence was contained within the uniquely-shaped visual search target. The target was often joined in the visual search display by a uniquely-coloured, task-irrelevant distractor. Results show a large and reliable congruency sequence effect - evidence that conflict resolution was facilitated - when a trial was preceded by high reward and the colours characterizing the target and distractor were the same as those in the previous trial. There was no corresponding congruency sequence effect after high reward when the target and distractor colours swapped. Strikingly, when low reward was received the opposite pattern emerged: conflict resolution was facilitated when context alternated but this effect was absent when context repeated.

These findings demonstrate how reward, by modulating contextual features, can have a direct impact on cognitive control. This type of direct influence is consistent with theoretical models of conflict monitoring such as the adaptation-by-binding account of Verguts and Notebaert (2008, 2009). According to this account, adaptations to conflict occur after response execution (but can initiate earlier, see e.g. Scherbaum, Dshemuchadse, Ruge, & Goschke, 2012), making them sensitive to feedback presentation and the environmental context present at that time. After high reward, the saliency of target contextual features is increased (or distractor contextual features after low reward). The Hebbian learning rule by which all active associations are enhanced after a conflict trial, as implemented in the model of Verguts & Notebaert (2008, 2009), can then be applied to explain context- and reward-sensitive adaptations to conflict, because it takes into account all active representations. The impact of reward on conflict adaptation identified in our results furthermore provides support for the idea that conflict adaptation is enhanced after a rewarding outcome (Braem et al., 2012; Sturmer et al., 2011). This general pattern has been interpreted as evidence that high reward may enhance the learning value of the conflict signal, creating a larger conflict adaptation effect. Low reward, in contrast, appears to devalue this learning signal and ultimately counteracts conflict adaptation. The current results also further corroborate studies demonstrating the general contextual selectivity of conflict adaptation (Braem et al., 2011; Spapé & Hommel, 2008; Verguts & Notebaert, 2008, 2009).

Although we believe that these results are most parsimoniously explained by the adaptation-by-binding model (Verguts & Notebaert, 2008, 2009), this experiment cannot - and was not set up to - differentiate between other models of cognitive control. The model of Botvinick et al. (2001) proposes that task focus is enhanced upon the detection of conflict. This model cannot explain the context-sensitivity of adaptations to conflict (our Experiment 1, see also Braem et al., 2011; Spapé & Hommel, 2008; Verguts & Notebaert, 2008, 2009). However, a relatively simple adjustment to the model can incorporate context or stimulus sensitivity (e.g., Blais et al., 2007). Note that the adaptation-by-binding model has a similar architecture as these models; it only specifies how the system retrieves information about which connections need to be strengthened (i.e., the most active ones). This information is not available in the original conflict monitoring model, nor in the model by Blais et al. (2007). These models, however, could assume that contexts that receive more attention by means of a reward manipulation show increased conflict adaptation. The adaptation-by-binding model assumes that conflict adaptation depends on levels of activation, and therefore explains the specific effect of rewarded/unrewarded contexts without additional assumptions. Note, that in this regard, the model bears some similarities to the feature binding account (Hommel, Proctor, & Vu, 2004). Both accounts assume that active features are bound, but the adaptation-by-binding account assumes that this binding is sensitive to conflict, in the sense that stronger binding occurs when conflict was detected. The feature-integration account, on the other hand, argues that the congruency sequence effect emerges from the mere repetition or alternations of stimulus features. However, our multiple regression analysis pointed out that these repetition effects could not explain, nor mediate, the influence of reward on context-sensitive congruency sequence effects.

On a more general level, we can interpret our findings in terms of a win-stay / lose-shift mechanism: good outcomes reinforce the current context while bad outcomes cause activation of the alternative context. Win-stay / lose-shift mechanisms have been suggested in other psychological and neuroscientific contexts to account for decision making (Nowak & Sigmund, 1993; Posch, 1999), animal behaviour (e.g., Evenden, & Robbins, 1984; Melis, Hare, & Tomasello, 2006), evolution psychology (e.g., Nowak, 2006), and prefrontal cortex activity (Bussey, Wise, & Murray, 2001; Genovesio, Brasted, & Mitz, 2005). Moreover, some theoretical work suggests that brain regions involved in stimulus-reward associations and win-stay / lose-shift strategies could participate in the attentional control of sensory information (Rossi, Pessoa, Desimone, & Ungerleider, 2009). However, to our knowledge, results from the study of attention and conflict monitoring have never before been interpreted within this framework. The current results suggest that the win-stay / lose-shift framework characterizes not only relatively high-level judgements and learning strategies, but also mechanisms that operate during low-level perceptual processing and conflict adaptation. When selection of a stimulus results in sub-optimal outcome, attentional templates appear to be changed such that perception is biased in favour of alternative stimuli and contexts. On the one hand, this ‘reward boost’ sets the stage for conflict adaptation to take place following context repetitions. On the other hand, the drive to reweight attentional templates after sub-optimal outcome creates a situation where performance is more efficient following context alternations, promoting adaptations to conflict under these circumstances. As noted by Hickey et al. (2010a), this type of mechanism has a clear evolutionary benefit, acting to bias perceptual and attentional processes in favour of stimuli and environments that have garnered good outcome and away from those that have garnered sub-optimal outcome.

It is important to point out that the current results, like those reported by Braem et al. (2012) and Stürmer et al. (2011), are strikingly at odds with those observed by Van Steenbergen et al. (2009; 2012). There the opposite pattern was found: conflict adaptation was evident after neutral and punishment trials, but absent after reward. This marked difference likely stems from some important differences in experimental design. In Van Steenbergen (2009; 2012) feedback took the form of a smiling or frowning schematic face, which indicated the receipt or loss of monetary value. Reward feedback thus had an affective and social importance that is absent in our design. Stimuli that induce positive affect have been found to cause increased task distractibility (Dreisbach & Goschke , 2004), and theoretical work on the motivation of adaptive behaviour has suggested fundamental differences in the impact of affective vs. reward feedback (Berridge & Robinson, 2003; Chiew & Braver, 2011). This raises the possibility that results from van Steenbergen et al. (2009; 2012) index the effect of emotional content rather than the motivational effect of reward, and highlights the need for further research investigating the precise influence of affective and reward feedback in conflict tasks.

In the current results the magnitude of the contextual impact of reward on cognitive control was partially predicted by the participant’s score on the BAS Reward Responsiveness subscale of the BIS/BAS personality assessment. The BIS/BAS scale requires participants to indicate the degree to which they agree with a number of short statements, and the reward responsiveness subscale loads heavily on statements that index a person’s affective response to reward feedback (eg. “When good things happen to me, it affects me strongly.”). The fact that contextual modulation of reward on cognitive control covaries with people's reward sensitivity provides clear support for the idea that reward impacts contextual effects in conflict monitoring. Conversely, we can also see this correlation as support for the idea that the effect of motivational and affective variables on cognitive control is still highly susceptible to individual differences, as has recently been stressed by Kanske (2012). Generally, the correlation identified in our study replicates results from Braem et al. (2012) and is consistent with earlier reports demonstrating a relationship between BAS subscales and the impact of reward on cognitive control and attentional selection (Hickey & Peelen, under review; Hickey, Chelazzi, & Theeuwes, 2010b; Van Steenbergen, Band, & Hommel, 2009).

In conclusion, we demonstrate that reward has an impact on conflict monitoring that is sensitive to visual context. We believe that this reflects an underlying role for reward in the control of attentional selection, directly influencing conflict adaptation processes. The type of win-stay / lose-shift mechanism identified in these results has a clear evolutionary benefit, guiding cognitive processing in favour of approaches and mechanisms that have garnered good outcome in the past. Reward - and its absence - clearly plays an important role in determining perception, attention, and cognitive control.

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CHAPTER 5

PUNISHMENT SENSITIVITY PREDICTS THE IMPACT OF PUNISHMENT ON COGNITIVE CONTROL [1]

Cognitive control theories predict enhanced conflict adaptation after punishment, either on the basis of the negative valence (Botvinick, 2007) or on the basis of increased arousal (Verguts & Notebaert, 2009). However, no such effect was found in previous work (Stürmer et al., 2011). In the present study, we demonstrate in a flanker task how behavioural adjustments following punishment signals are highly dependent on punishment sensitivity (as measured by the Behavioural Inhibition System (BIS) scale): Whereas low punishment-sensitive participants do show increased conflict adaptation after punishment, high punishment-sensitive participants show no such modulation. Interestingly, participants with a high punishment-sensitivity did show an overall reaction time increase after punishments. Our results stress the role of individual differences in explaining motivational modulations of cognitive control.

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[1] Braem, S., Duthoo, W., & Notebaert, W. (revision submitted). Punishment predicts the impact of punishment on cognitive control.

INTRODUCTION

The subject of cognitive control, the ability to monitor our environment and adapt to ever-changing contexts, has been of increasing interest to psychologists over the past decades. However, the interactions between cognitive-control mechanisms and motivational variables are not well understood. Previous studies have demonstrated how overall conflict processing (Krebs, Boehler, & Woldorff, 2010), as well as adaptations to conflict (Braem, Verguts, Roggeman, & Notebaert, 2012; Stürmer, Nigbur, Schacht, & Sommer, 2011), can be enhanced after reward. While we have these first notions on the role of reward in modulating cognitive control, the influence of punishment on conflict adaptation remains unclear. However, we encounter negative feedback all the time (e.g., annoying computer beeps indicating wrong key presses) and it is important to understand how these signals interact with cognitive processes. In the present study, we set out to investigate if, how, and when, punishment can modulate trial-to-trial adaptations to cognitive conflict.

In research on cognitive control, conflict tasks are typically used. In the flanker task (Eriksen & Eriksen, 1974), for example, in which the central target is presented together with either congruent (> > >) or incongruent (> < >) flankers, participants respond faster and more accurately on congruent trials compared to incongruent trials (i.e., the flanker effect). Interestingly, Gratton, Coles, and Donchin (1992) observed that there was a smaller flanker effect after incongruent than after congruent trials (termed the conflict adaptation or Gratton effect). There are a number of different frameworks dealing with this Gratton effect and we will discuss three of the most prominent theoretical models. These models all differ in describing the exact mechanics for explaining the Gratton effect, and the role of motivational variables there-in. Interestingly, however, all three models predict a similar modulation by punishment.

According to the Conflict Monitoring Theory (CMT, Botvinick, 2007; Botvinick, Braver, Barch, Carter, & Cohen, 2001), conflict, as an aversive signal (Dreisbach & Fischer, 2012a; Fritz & Dreisbach, in press; Schouppe, De Houwer, Ridderinkhof, & Notebaert, 2012), is detected by the anterior cingulate cortex (ACC) which triggers subsequent behavioural adaptation by enhancing focus to task-relevant information, implemented by the dorsolateral prefrontal cortex. The CMT suggests that the aversiveness of cognitive conflict is what drives conflict adaptation (Botvinick, 2007). In support of this view, stressing the importance of negative valence in bringing about adaptations to conflict, van Steenbergen, Band, and Hommel (2009, 2010, 2012) demonstrated how positive affect can counteract the Gratton effect. Therefore, a similar but aversive teaching signal would add to this signal (van Steenbergen et al., 2009, 2010, 2012) and thereby enhance conflict adaptation, resulting in a more pronounced Gratton effect.

As an alternative account of cognitive control, the adaptation-by-binding account (ABBA) of Verguts and Notebaert (2009) suggests that conflict strengthens currently active connections. In this model, an arousal signal is sent throughout the brain upon the detection of cognitive conflict (Compton, Arnstein, Freedman, Dainer-Best, & Liss, 2010), which strengthens, through Hebbian learning, all active task-relevant connections. By binding these associations after conflict, a smaller congruency effect will occur on the following trial, reflected in the Gratton effect (Verguts & Notebaert, 2008, 2009). The ABBA predicts that arousing stimuli, irrespective of their valence, would help to increase adaptations following conflict (Verguts & Notebaert, 2009). Therefore, this account also hypothesizes that punishment signals would enhance the Gratton effect.

While both the CMT and ABBA focus on reactive control (adjusting information processing after the detection of conflict), Braver, Gray and Burgess (2007) make a distinction between proactive and reactive modes of cognitive control (Dual Mechanisms of Control or DMC, see also Braver, 2012). Whereas proactive control refers to a more anticipatory mode of cognitive control, where priorities are set before the occurrence of the cognitive conflict, reactive control refers to the mode of control driven by situational events, for example, the trial-by-trial adaptations to cognitive conflict as described above. This dissociation is important, because the DMC predicts that the proactive and reactive modes of cognitive control are differentially affected by motivational variables. Specifically, the DMC framework predicts that rewards promote proactive control, while punishments enhance reactive control (Braver, 2012; Braver, Paxton, Locke, & Barch, 2009; Locke & Braver, 2008). Therefore, conceptualizing the Gratton effect as a manifestation of reactive control, we can again predict that punishments will enhance adaptations to conflict.

However, although all three models seem to predict a similar modulation by punishment, a first study investigating the modulation of the Gratton effect by punishment signals (Stürmer et al., 2011) showed no modulation, whereas reward signals effectively enhanced the Gratton effect (see also Braem et al., 2012). Interestingly, Stürmer et al. (2011) observed an overall reaction time increase after punishments, rather than increased conflict adaptation. This suggests that punishment distracted participants from the task, similar to what happens after participants make an error (Houtman, Núñez Castellar, & Notebaert, 2012; Notebaert et al., 2009). Consequently, it is possible that punishments are perceived as too salient, slowing down subsequent performance rather than increasing task focus.

As a first test of this hypothesis, we take individual differences in sensitivity to punishment into account. As recently stressed in a review on the influence of emotion and motivation on cognitive conflict (Kanske, 2012), individual differences in sensitivity to emotional or motivational stimuli have a major impact on how such signals modulate conflict processing. Therefore, we hypothesized that the influence of punishment on performance should vary as a function of punishment sensitivity. In order to assess punishment sensitivity in the present study, we administered the BIS- (Behavioural Inhibition System) and BAS-scales (Behavioural Activation

System; Carver & White, 1994), which have proven to be valuable tools in predicting how individual differences in punishment or reward sensitivity can modulate motivational effects on cognition (e.g., Amodio, Master, Yee, & Taylor, 2008; Boksem, Tops, Kostermans, & De Cremer, 2008; Boksem, Tops, Wester, Meijman, & Lorist, 2006; Braem et al., 2012; Cavanagh, Frank, & Allen, 2010; De Pascalis, Varriale, & D'Antuono, 2010; Hickey, Chelazzi, & Theeuwes, 2010b; van Steenbergen et al., 2009). Specifically, we predicted that increased cognitive control following punishment would be restricted to participants that are not highly sensitive to punishment, while participants that are scoring high on BIS will probably not benefit or learn from punishments, and, if anything, show a decrease in task performance.

To this end, we opted to use exactly the same design as in our reward study (Braem et al., 2012), in which a four-choice colour flanker experiment was combined with reward signals on 25 % of the trials. Yet, instead of these rewards, we now presented punishments. Participants were informed that 25 % of the trials could be punished. This was to keep punishment expectations similar across participants. Yet, when participants responded very fast and accurate, a punishment could be avoided. This implementation of punishments ensures that punishment signals are randomly distributed, but still performance-contingent. In our opinion, this schedule is preferable to a punishment schedule where the 25% slowest responses are punished (as used in Stürmer et al., 2012) where it can be difficult to disentangle the direct effects of punishment presentation versus the impact of previous task performance.

Furthermore, we chose to present punishment signals without an inherent affective value (we presented "-1", denoting the loss of a point in the participants' score). This was to ensure that we were investigating the modulation of cognitive control by punishment, rather than negative affect (i.e., by presenting a negative smiley as a punishment signal, our effect of punishment could be confounded with an effect of negative affect that is not punishment-induced). As argued in our previous reward study (Braem et al., 2012), affective and reinforcement signal modulations of cognitive control should be distinguished from one another (see also Berridge and Robinson, 2003; Chiew and Braver, 2011). For example, where we observed an enhancement of the Gratton effect after reward, the studies of van Steenbergen et al. (2009, 2012) demonstrated a reduced Gratton effect after positive affect (for a review on this differential impact of affective and reinforcement signals on conflict adaptation, see Dreisbach & Fischer, 2012b).

In sum, we administered a flanker task with performance-contingent punishment signals and verified whether punishment sensitivity, as measured by the BIS-scale, modulated punishment-induced modulations of cognitive control.

METHOD

Participants

Twenty-six students took part in return for credits or 6€ (range = 18-21 years, 22 female, 22 right-handed) based on their written informed consent with approval of the local ethical committee and according to the Declaration of Helsinki.

Stimuli and Material

The flanker stimuli consisted of three horizontally aligned, centrally presented squares that were printed in one of the four possible colours (green, yellow, blue or red). Both flankers had either the same (congruent: e.g., red-red-red) or a different (incongruent: e.g., blue-red-blue) colour than the central square. The stimuli were presented on a Pentium, with the use of Tscope software (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 2006). A hand response box was used to register the responses.

Procedure and Design

Participants were asked to respond to the colour of the central square by pressing one of the four horizontally aligned response buttons, using their index and middle fingers. Subjects were randomly assigned to one of four response mappings, which were created by shifting the colour-to-button assignment. After a practice block of 48 trials, participants performed 14 experimental blocks of 48 trials. For each experimental block, an equal number of congruent and incongruent trials were presented in a random order: 25% of the trials were punishment trials, which were randomized for the congruent and incongruent trials separately. Between blocks, participants were allowed a self-paced break during which they could see their updated score. For every ten participants, the participant with the best score received a store coupon worth 10€. Each subject started with a score of 300 points and could only lose points on punishment trials, as indicated by feedback presentation in the form of "-1". Hence, whenever seeing "-1" participants knew that they just lowered their chances of winning a store coupon. There was no option to gain points. All participants were truthfully instructed about this reinforcement schedule.

First, a fixation cross was presented for 500 milliseconds, after which the target and flanker stimuli were presented and remained on the screen until the participant responded. The maximum response time was 1000 milliseconds. On punishment trials, the participant was given feedback in the form of “-1” centrally presented on the screen for 500 milliseconds, unless he or she responded correctly faster than 350 milliseconds[2]. In the latter case, or after a “no-punishment” trial, a blank screen was presented for 500 milliseconds. Finally, a blank screen was presented for 1000 milliseconds, whereupon the next trial started.

Questionnaires

Immediately after the experiment, participants completed the Behavioural Inhibition System/Behavioural Activation System (BIS/BAS) Scales (Carver & White, 1994). This took the form of 20 questions, such as "I feel worried when I think I have done poorly at something important" and "When I get something I want, I feel excited and energized", respectively examining punishment and reward sensitivity. Seven items score punishment sensitivity, averaged into a BIS-score, for which higher values indicate higher punishment sensitivity. The thirteen remaining items all score reward sensitivity (BAS-score), sometimes divided into its three subscales: BAS Reward Responsiveness (5 items), BAS Drive (4 items), and BAS Fun (4 items). A higher value on these scales indicates a higher form of reward sensitivity.

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[2] Although participants knew from the instructions that the punishment signals were performance-contingent, we wanted to ensure that participants also experienced those as such. In the reward version of this experiment (Braem et al., 2012), people missed out on their reward on 10 % of the potential rewarding trials. We believe that this 10 % is enough for participants to feel that their reinforcement signals are performance-contingent. Therefore, we aimed at enabling participants to escape their punishments in 10 % of the trials. In this light, the 350 milliseconds deadline was chosen, because earlier versions of this experiment (Braem et al., 2012) showed that only 10% of the responses were faster than 350 milliseconds. Indeed, also in the present experiment, participants were faster than 350 milliseconds on only 10.8% of the trials.

RESULTS AND DISCUSSION

One participant was excluded from the analysis because of a mean accuracy (= 0.45) two standard deviations below the group average (*M* = 0.76; *SD* = 0.12). Trials following an error and the first trial of each block were removed from further analyses (24.5% of the trials). Also, trials following a trial where the response time (RT) was faster than 350 milliseconds were also excluded (another 8.4% of the remaining trials) to ensure that the effect of previous feedback was not confounded with previous RT (trials faster than 350 milliseconds were never punished). For the RT analyses, errors were also excluded (13.2% of the remaining trials) and from these remaining trials, RT outliers (± 2*SD* of the mean reaction time calculated per subject) were removed (2.2%). This means that a total of 48.3% of the trials were excluded for the RT analyses, primarily due to the relatively high error rate (24%) in this experiment. This observed error rate is clearly higher than the reward version of our experiment (10%, Braem et al. 2012). Conversely, reaction times were substantially faster (480 ms) in our punishment experiment, as compared to the reward experiment (530 ms). We believe that this main difference in task performance represents an important dissociation in response strategy elicited by the different reward and punishment conditions (see also, Gomez & Mclaren, 1997; Locke & Braver, 2008). However, excluding this high number of trials did not influence our main findings (removing the two participants with less than ten data points in one condition from the analyses did not change the significance of our main correlation).

Next, we carried out an ANOVA with three within-subject factors (congruency, previous congruency and previous feedback), with RTs and error rates as dependent variables. We observed a significant congruency effect, $F(1,24) = 72.706$, $p < .001$, which interacted with previous congruency, $F(1,24) = 26.053$, $p < .001$, indicating a significant overall Gratton effect of 17 ms (as calculated by subtracting the congruency effect after incongruent trials from the congruency effect after congruent trials).

Although the Gratton effect after punishments was numerically larger than the Gratton effect after no-punishment trials (23 vs. 12 ms, respectively), this modulation did not reach significance, *F*(1,24) = 1.682, *p* > .1. The error rates only showed a significant congruency effect, *F*(1,24) = 14.698, *p* < .01. It could be argued that the feedback presentation on punishment trials (versus blank screen on no-punishment trials) in our experiment might have counteracted an overall modulation of the Gratton effect. However, our findings are in line with the study of Stürmer et al. (2011), who did present feedback after neutral trials. Furthermore, in our previous study (Braem et al., 2012), we ran two control studies that demonstrated how infrequent irrelevant stimulus presentations (vs. no visual stimulation) during the inter-trial interval did not modulate adaptations to conflict.

Next, we wanted to investigate how individual differences in punishment sensitivity (as measured by the BIS-scale) modulate the effect of punishment on conflict adaptation. To this end, we included the three covariates BIS-score, BAS-score, and mean (correct) reaction time, in our overall ANOVA. While the BIS- and BAS-scores were included to investigate the influence of punishment and reward sensitivity, respectively, the inclusion of mean reaction time as a covariate was mainly to control for individual differences in sensory-motor variability. As predicted, the analysis demonstrated a significant interaction with previous feedback, previous congruency, current congruency and the covariate BIS, *F*(1,21) = 5.833, p < .05, but not with BAS, nor mean reaction time (both *F*'s < 1), suggesting that our main result of interest could not be explained by differences in reward sensitivity or overall response speed between participants. The relation between BIS and cognitive control is depicted in Figure 1, where the correlation between the modulation of the Gratton effect (as calculated by subtracting the Gratton effect after no-punishment trials from the Gratton effect after punishment trials) and participants' punishment sensitivity (ρ = -.410, p < .05) is plotted. No Spearman's rho correlations were observed with the BAS-scale, any of its subscales, or mean reaction time (all p > .1). Both the correlation with BIS and the Gratton effect after punishment, ρ = -.310, p = .131 as well as the correlation with BIS and the Gratton effect after no-punishment trials, ρ = .327, p = .110, did not reach significance, suggesting that punishment sensitivity specifically correlated with the difference in behavioural modulation following punishment and no-punishment trials.

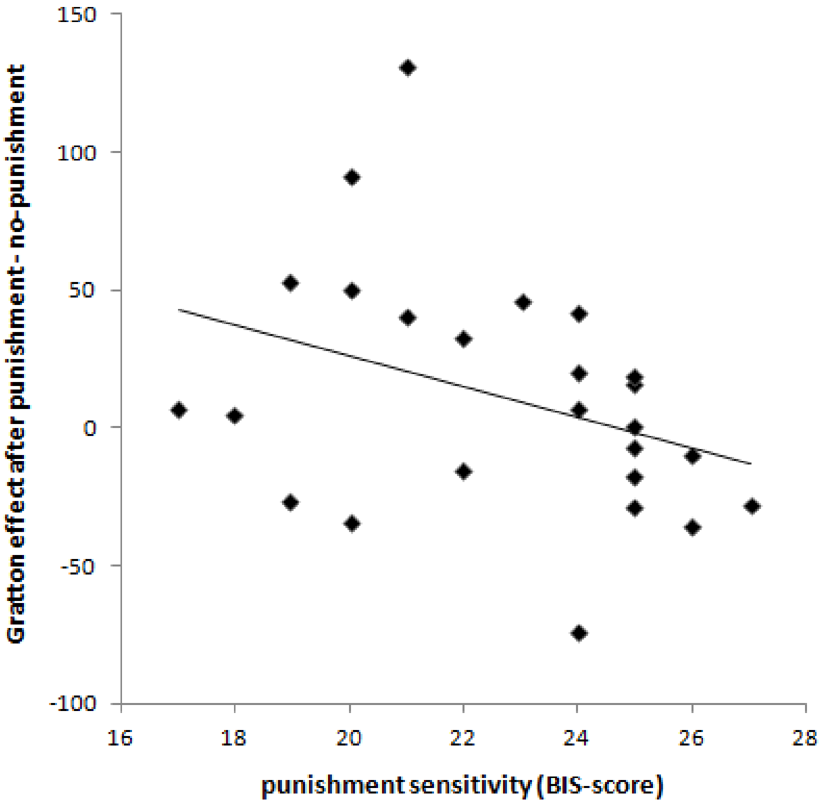

Figure 1. The scatter plot shows the correlation between individual scores on the BIS scale and the difference in Gratton effects.

To further investigate the role of punishment sensitivity in the modulation of the Gratton effect, we decided to split up our subjects in a low and high punishment-sensitive group by means of a median-split analysis on participants' BIS-score: participants with a BIS-score lower than 24 were assigned to the low punishment-sensitive group and participants with a BIS-score of 24 or higher were assigned to the high punishment-sensitive group. Note that the mean BIS-score (20.2) for the low punishment-sensitive group is actually similar to the average BIS-scores collected from large community samples, which are typically between 19 and 22 (Johnson, Turner, & Iwata, 2003; Jorm et al., 1998). The mean BIS-score (25) for the high punishment-sensitive group on the other hand, can be considered relatively high. Next, we re-analysed our data with punishment sensitivity as a between-subjects factor.

In line with the observed correlation, we found a four-way interaction between congruency, previous congruency, previous feedback, and punishment sensitivity in reaction times, $F(1,23) = 5.991$, $p < .05$. Interestingly, the error rates showed a similar trend, $F(1,23) = 3.253$, $p = .084$. Moreover, a marginally significant effect hinted at a second modulation of punishment sensitivity on the main effect of previous feedback, $F(1,23) = 3.571$, $p = .071$, indicating slowing after punishment in the high punishment-sensitive group, but not in the low punishment-sensitive group. No other effects of punishment sensitivity were observed (all *p*s > .1).

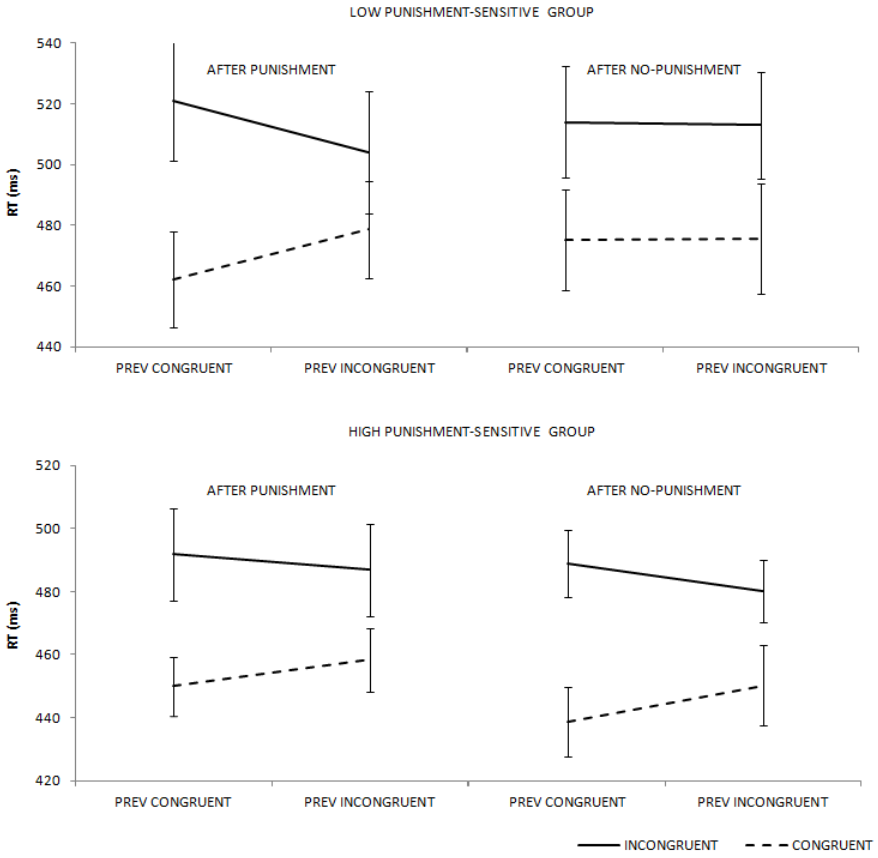

Figure 2. The reaction times for each punishment-sensitive group separately. The figure demonstrates how punishment helps in adapting to conflict, for low punishment-sensitive people, while people high in punishment sensitivity slow down after punishment. The error bars are ± 1 standard error.

In order to gain further insight in these behavioural differences between both punishment sensitivity groups, we conducted ANOVAs for each punishment sensitivity group separately. As depicted in Figure 2, the low punishment-sensitive group showed a modulation of the Gratton effect, $F(1,11) = 5.159$, $p < .05$: the Gratton effect after punishment trials (33 ms) was more pronounced than the Gratton effect after no-punishment trials

(2 ms; this absence of a Gratton effect after no-punishment trials will be discussed in the general discussion). The high punishment-sensitive group, on the contrary, showed an overall significant Gratton effect, *F*(1,12) = 11.305, *p* < .01, that was not modulated by previous feedback, *F*(1,12) < 1. However, a main effect of previous feedback indicated that the high punishment-sensitive group did show a general slowing after punishments, *F*(1,12) = 7.309, *p* < .05, whereas the low punishment-sensitive group did not, *F*(1,11) < 1. The modulation of the Gratton effect per punishment-sensitivity group in the error rates, as well as each Gratton effect separately, garnered no significant results in both conditions, but followed a numerically similar trend as the reaction times, as summarized in Table 1.

Alternatively, instead of exploring the four-way interaction between congruency, previous congruency, previous feedback, and punishment sensitivity, by looking at the separate punishment-sensitivity groups, we also performed analyses on the effects of punishment sensitivity on the Gratton effect, after punishment and no-punishment trials separately. The Gratton effect after punishment was not significantly larger in the low punishment-sensitive than in the high punishment-sensitive group, *F*(1,23) = 2.546, *p* = .124. After no-punishment trials, however, the Gratton effect was significantly smaller in the low punishment-sensitive group than in the high punishment-sensitive group, *F*(1,23) = 5.538, *p* = .028. This interaction hint at differences in the respective Gratton effects. Therefore, we tested the Gratton effects in all four conditions separately. Interestingly, the Gratton effect after punishment in the high punishment-sensitive group did not reach significance, *F*(1,12) = 3.069, *p* = .105, while the same Gratton effect in the low punishment-sensitive group did, *F*(1,11) = 10.883, *p* < .01. Specifically, post-hoc t-tests showed a significant slow-down (17 ms) of congruent trials after punished incongruent trials, *t*(12) = 5.042, *p* < .001, as compared to after punished congruent trials. The decrease in reaction times on incongruent trials after punished incongruent trials (17 ms) in the low punishment-sensitive group, *t*(12) = 1.659, *p* = .125, did not reach significance. The Gratton effect after no-punishment trials in the high punishment-sensitive group was significant, $F(1,12) = 15.121$, $p < .01$, while this Gratton effect in the low punishment-sensitive group was not, $F(1,11) < 1$. Specifically, in the high punishment-sensitive group a significant slow-down (12 ms) of congruent trials after unpunished incongruent trials was observed, $t(12) = 4.276$, $p < .01$, as well as a marginally significant speed-up (9 ms) of incongruent trials after unpunished incongruent trials, $t(12) = 2.048$, $p = .063$.

Table 1. Mean error rate (%) as a function of previous congruency, current congruency and preceding feedback for each punishment sensitivity group differently.

		low punishment-sensitive group		*high punishment-sensitive group*	
n-1	*n*	*after punishment*	*after no-punishment*	*after punishment*	*after no-punishment*
C	C	16.8	19.5	18.5	15.0
	I	25.4	23.3	21.9	22.1
I	C	21.6	19.8	13.6	17.3
	I	22.9	23.4	24.4	21.5

Note: C = congruent; I = incongruent; *n* - 1 = preceding trial; *n* = current trial.

GENERAL DISCUSSION

In line with previous studies (Stürmer et al., 2011), a group analysis of the current study suggested that punishment signals do not influence adaptations to conflict. However, by taking into account individual differences in punishment sensitivity, we have demonstrated how punishment can have an effect on cognitive control, depending on the punishment's perceived severity. Participants low in punishment-sensitivity showed an enhanced Gratton effect after punished trials. Participants high in punishment-sensitivity showed no such modulation. Instead, highly punishment-sensitive participants slowed down after punishments.

Our results clearly stress the importance of taking into account individual differences when studying the role of motivational variables in modulating cognitive control (Kanske, 2012). Especially when investigating motivational or emotional influences on cognitive control, individual differences in sensitivity can help expose underlying mechanisms of how these variables influence cognitive adaptations (e.g., Amodio, Master, Yee, & Taylor, 2008; Boksem, Tops, Kostermans, & De Cremer, 2008; Boksem, Tops, Wester, Meijman, & Lorist, 2006; Braem et al., 2012; Cavanagh, Frank, & Allen, 2010; De Pascalis, Varriale, & D'Antuono, 2010; Hickey, Chelazzi, & Theeuwes, 2010b; van Steenbergen, Band, & Hommel, 2009). For example, using electrophysiological recordings, De Pascalis, Varriale, and D'Antuono (2010) demonstrated a higher feedback-related negativity following punishments as a function of participants' BIS-score. Boksem, Tops, Kostermans, and De Cremer (2008) investigated the influence of punishment sensitivity (as measured by the BIS-scale) on behavioural adaptations after punished performance errors and demonstrated how high punishment-sensitive people show more slowing after punishments than low punishment-sensitive people do. Our results add to these findings by demonstrating that punishments can also promote adaptive behaviour, as long as people are not too sensitive to punishments.

Surprisingly, in the low punishment-sensitive group, the modulation of the Gratton effect was not only reflected in a larger Gratton effect after punishments, but also an absent Gratton effect after no-punishment trials. This finding is in line with earlier studies investigating motivational effects on cognitive control, in that these studies also demonstrated how the motivationally less significant condition is not the neutral and constant baseline as sometimes assumed (e.g., Braem et al., 2012; Hickey, Chelazzi, & Theeuwes, 2010a; 2011; Muhle-Karbe & Krebs, 2012). Instead, by introducing a motivationally significant reinforcement signal, a context is created where both punishment and no-punishment trials receive an informative value: by increasing the motivational value of punishment trials the value of no-punishment trials is simultaneously decreased.

At first sight, our findings might sound counterintuitive in suggesting that higher sensitivity to a reinforcement signal is associated with lower benefits of this reinforcement signal on task-adaptive behavior. Instead, task-performance seems to be impeded, rather than promoted after punishment for high punishment-sensitive people. Therefore, we believe our results might reflect the right hand side of an inverted-U shaped function between punishment saliency and task performance. Too often, existing theories of cognitive psychology assume a linear, more-is-better effect of cognitive variables (e.g., medication, reward, working memory capacity, etc.) on performance, whereas both empirical progress (Grant & Schwartz, 2011) and evolution theory (Hills & Hertwig, 2011) have indicated it is wise to assume a curvilinear, inverted U-shape function. Our findings corroborate this idea: by taking into account punishment sensitivity, we demonstrated how we are able to flexibly adapt our behaviour after punishments, as long as they don't overwhelm us.

Specifically, our findings could be framed within the Yerkes-Dodson law (Yerkes & Dodson, 1908), which suggests that there is an inverted U-shaped relation between arousal and task performance. Reinforcement signals that are too arousing will decrease, rather than increase, task performance. We can interpret our data as an extension of the Yerkes-Dodson law, in the sense that not only general task performance is modulated by a curvilinear function of arousal, but also cognitive control is (i.e., trial-to-trial adaptations to conflict). This, however, does not mean that our findings can exclusively be explained in terms of the ABBA, which describes adaptations to conflict as a function of (conflict-induced) arousal. In fact, the arousing value of a punishment might as well directly impact the experienced aversiveness (Botvinick, 2007) or the saliency with which it will promote reactive control (Braver, 2012).

We suggest that for the low punishment-sensitive group of participants that showed an enhanced Gratton effect following punishment signals, punishments induced the appropriate levels of saliency for increasing cognitive control. This modulation could reflect an enhanced strengthening of task relevant associations (Verguts & Notebaert, 2008; 2009), a modulation of task attention (Botvinick et al., 2001; Botvinick, 2007), or a shift from a more proactive to a more reactive control modus (Braver et al., 2009), after punishment. However, participants highly sensitive to punishment showed no modulation of the Gratton effect after punishment, suggesting that arousal levels were too high to modulate cognitive control processes. These participants showed an overall increase in response latencies following punishment. This finding is in line with Stürmer et al. (2011). Similarly, Padmala, Bauer, and Pessoa (2011) showed how arbitrarily presenting highly arousing negative pictures (i.e., pictures of mutilated corpses) in between Stroop trials, elicited an overall reaction time slowing, and even a reduced conflict adaptation effect.

The overall differential influence of punishment and reward signals, in that reward signals modulate adaptations to conflict (Braem et al., 2012; Stürmer et al., 2011) while punishment signals do not (Stürmer et al., 2011; our overall analysis), could also be attributed to a difference in arousal levels induced by both reinforcement signal types. For example, keeping everything else equal, Gomez and McLaren (1997) systematically examined the effects of reward and punishment signals and demonstrated how punishment schedules (as opposed to reward schedules) induced higher overall arousal levels, as measured by the skin conductance response. Similarly, comparing appetitive with aversive motivational systems, Tranel (1983) demonstrated how the latter was associated with an increased skin conductance response, while the former was not. These findings are also consistent with the more general idea of a negativity bias, which relates to the finding that people tend to pay more attention and give more weight to negative, as compared to positive, experiences (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Rozin & Royzman, 2001).

In fact, this apparent different impact of rewards and punishments may reflect a similar difference observed between post-conflict and post-error behavioural adjustments. While cognitive conflict seems to help task focus, errors elicit an orienting response, causing an overall slowing rather than enhanced performance (Notebaert & Verguts, 2011). Interestingly, both post-error and post-conflict processes have been linked to arousal (e.g., Carp & Compton, 2009; Compton, Arnstein, Freedman, Dainer-Best, & Liss, 2010; Notebaert et al., 2009; Nunez Castellar, Kühn, Fias, & Notebaert, 2010, Verguts & Notebaert, 2009), yet conflict-induced arousal, although reliable, seems to be substantially smaller than error-induced arousal (Compton, Arnstein, Freedman, Dainer-Best, & Liss, 2010). Similar to error processing, we suggest that people highly sensitive to punishment may have experienced a short-lived orienting response (Notebaert et al., 2009) towards the punishment signal, but away from the task, reflecting a failure to disengage from the punishment. Analogously, it has been demonstrated that high punishment-sensitive people attend longer to aversive stimuli and have difficulty disengaging attention from these stimuli (Poy, Eixarch, & Ávila, 2004).

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CHAPTER 6

NO PAIN, NO GAIN: THE BIVALENT AFFECTIVE NATURE OF COGNITIVE CONFLICT[1]

The cognitive control theory of Botvinick (2007) integrates cognitive and affective control processes by emphasizing the aversive nature of cognitive conflict. Using an affective priming paradigm, we replicate earlier results showing that conflict is indeed perceived as aversive (Dreisbach & Fischer, 2012). Importantly, in two experiments we show that this negative affect switches into positive affect after responding successfully to a conflict-inducing stimulus. Furthermore, in a control experiment, we demonstrate that this positive affect only occurs after resolving conflict, and not merely after correctly responding to difficult trials. The results are discussed in light of a computational model (Silvetti, Seurinck, & Verguts, 2011) in which it is assumed that outcome expectancies are more negative for incongruent trials than congruent trials. Hence, the reward after successful completion is larger for incongruent than congruent trials. These findings divulge a novel perspective on cognitive adaptations to conflict.

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[1] Schouppe, N.*, Braem, S.*, De Houwer, J., Silvetti, M., Verguts, T., & Notebaert, W. (under revision). No pain, no gain: The bivalent affective nature of cognitive conflict. Cognition. *both authors contributed equally

INTRODUCTION

Cognitive control models have developed from ‘cold’ models, assigning no role to affective modulations (Atkinson & Shiffrin, 1968; Baddeley, 1986, 2007; Norman & Shallice, 1986; Shiffrin & Schneider, 1977), to models integrating cognition and emotion (e.g., Botvinick, 2007; Gray, 2004; Verguts & Notebaert, 2009). An integration between both domains is supported by numerous neuroimaging studies, showing for instance that the anterior midcingulate cortex (aMCC), an area thought to be a central node in the cognitive control network (Botvinick, Braver, Barch, Carter, & Cohen, 2001), is also activated during the experience of negative affect and pain (for a review see Shackman et al., 2011).

Cognitive control studies typically use congruency tasks to investigate the processing of, and adaptation to conflict (e.g., flanker task, Eriksen & Eriksen, 1974; Stroop task, Stroop, 1935; Simon task, Simon, 1969). In these tasks, conflict is induced by competition of a task-relevant dimension with an irrelevant to-be-ignored stimulus feature. For instance, in the Stroop task, participants have to name the ink colour of a word (relevant dimension), while ignoring the meaning of the word (irrelevant dimension). The processing of this irrelevant dimension can facilitate task performance when being congruent with the relevant dimension, as when the word meaning and ink colour correspond (e.g., ‘RED’ in red ink). On incongruent trials, however, there is a mismatch between word meaning and ink colour (e.g., ‘RED’ in blue ink), inducing a cognitive conflict that impedes task performance. Interestingly, it has recently been suggested that such conflicts between processing dimensions are aversive and thus evoke negative affective reactions (Botvinick, 2007; Corr, 2008). Furthermore, Botvinick (2007) suggested that this aversive nature of conflict triggers subsequent behavioural adaptations. Consistently, van Steenbergen, Band, and Hommel (2009, 2010) demonstrated that cognitive adaptations after incongruent trials can be counteracted by positive mood.

Several recent studies support the notion of conflict aversiveness. Lynn, Riddle, and Morsella (2012) showed that participants reported a greater urge to quit the task at hand after incongruent Stroop trials, than after congruent Stroop trials. Similarly, in a colour Stroop task where participants had to let their computer avatar walk towards or away from the stimulus, Schouppe, De Houwer, Ridderinkhof, and Notebaert (2012) showed a reduction of the Stroop effect when participants had to walk away from the Stroop stimulus (relative to approaching), suggesting that, in the face of conflict, avoidance is the more likely response. Using a variation of the Simon task, Cannon, Hayes, and Tipper (2010) found that responding to response compatible stimuli evoked greater activity of the zygomaticus muscle (associated with smiling) than to response incompatible stimuli. They also reported the activity of the corrugator muscle (associated with frowning) and found a trend suggesting greater activity after incompatible reactions than compatible reactions (but see Schacht, Dimigen, & Sommer, 2010, who failed to obtain such an effect). Similarly, Brouillet, Ferrier, Grosselin, and Brouillet (2011) used an affective priming paradigm, typically applied to measure the affective value of stimuli (Fazio, 2001), and showed that action compatible trials are indeed positively evaluated compared to action incompatible trials. In this task, participants evaluated the valence of target words (e.g., joy) that were preceded by graspable objects as primes. Participants were faster to evaluate positive (compared to negative) words, when the orientation of the handle of the object was compatible with the response hand for target evaluation. Dreisbach and Fischer (2012) recently also used an affective priming paradigm but with congruent and incongruent Stroop stimuli as primes. Importantly, they found a negative affective priming effect after incongruent primes. Thus, although participants did not respond to the prime (i.e., Stroop) stimuli, they were faster to categorise a negative target word after an incongruent prime than after a congruent prime. Conversely, participants were slower to evaluate a positive target when it was preceded by an incongruent prime compared to a congruent prime. These results thus suggest that incongruent trials are indeed registered as more negative than congruent stimuli.

In their reward value and prediction model (RVPM) of the anterior cingulate cortex (ACC), Silvetti, Seurinck, and Verguts (2011) provided a neuro-computational account for the affective connotation of conflicting situations. They proposed that incongruent trials evoke negative prediction error signals (negative surprises) in the ACC due to the longer reaction times needed to respond to incongruent stimuli, and to the higher probability of an error response (see also Alexander & Brown, 2011). As a consequence of frequent negative prediction errors, the success (or reward) expectation evoked by an incongruent stimulus is lower than that evoked by a congruent one. Interestingly, the RVPM also predicts that once an incongruent trial is correctly solved, it evokes a positive prediction error signal (positive surprise) that is larger than on congruent trials. This model thus predicts a shift from a negative to a positive prediction error after conflict resolution (i.e., responding correctly to an incongruent stimulus), and interprets the conflict-related ACC activation as the conjoined effect of both negative and positive prediction error signals.

Hence, the model predicts that cognitive tasks can induce both positive and negative evaluative signals. In line with this idea, Kennerley, Behrens, and Wallis (2011) showed that neurons in monkey ACC exhibit a switching response pattern within a trial. For example, if a neuron encodes reward probability positively during the cue period (higher probability, stronger response), it responds as an inverse function during positive feedback (higher probability, weaker response). Similarly, Satterthwaite et al. (2012) recently suggested that people experience intrinsic reinforcement during standard cognitive tasks, even in the absence of a reward manipulation. Using a working memory task, they demonstrated how the ventral striatum, known for its central role in motivation and reinforcement learning, responded to task performance as a function of task difficulty, in the sense that correct responses on more difficult trials resulted in higher ventral striatum activation. Furthermore, Molapour and Morsella (2010) observed that nonsense shapes that co-occurred with incongruent Stroop stimuli were preferred over shapes that co-occurred with congruent or neutral Stroop stimuli. Crucially, and in contrast to the study of Dreisbach and Fischer (2012), participants had to respond to each Stroop stimulus. Responding to an incongruent Stroop stimulus allowed participants to resolve the cognitive conflict that was induced by this stimulus. As predicted by Silvetti et al. (2011), conflict resolution might result in a positive affective state, which would transfer to the shapes that were paired with incongruent Stroop stimuli. However, the findings of Molapour and Morsella provide at best indirect evidence for the potentially rewarding role of conflict resolution. We therefore set out to examine this issue more directly.

In the first experiment, we wanted to replicate the findings of Dreisbach and Fischer (2012) using a combination of a flanker task and an affective priming task. Each trial started with the presentation of a congruent or incongruent flanker (prime) stimulus that did not require a response. Congruent flanker stimuli consisted of arrows that all pointed in the same direction. In incongruent flanker stimuli, the central arrow pointed to a different direction than the other arrows. Immediately following the flanker stimulus, a positive or negative word was presented that had to be evaluated as positive or negative. Because observation is sufficient for conflict detection (van Schie, Mars, Coles, & Bekkering, 2004; Winkel et al., 2009, 2012), we can assume that incongruent flanker trials would elicit conflict while congruent flanker primes would not. Moreover, to ensure that participants associated incongruent trials with conflict, a normal flanker task preceded each experimental block where participants did have to respond to the flanker stimuli. Similar to Dreisbach and Fischer, we predicted negative affective priming (i.e., relative to congruent primes, incongruent primes facilitate responding to negative targets).

In the second experiment, participants first had to respond to the congruent and incongruent flanker stimulus (i.e., they were instructed to indicate the direction of the central arrow) before making an affective judgment. In this case, we predicted positive affective priming (i.e., relative to congruent primes, incongruent primes facilitate responding to positive targets), because the conflict elicited by the incongruent primes had to be resolved.

Furthermore, in order to verify that the difference in affective priming between Experiment 1 and 2 was due to conflict resolution rather than the mere act of responding to the primes, we conducted Experiment 3 in which participants made a similarity judgement to the prime stimuli (i.e., determine whether the flanker arrows point in the same direction as the central arrow). Hence, participants could respond to the primes without resolving the conflict induced by incongruent primes. If successful conflict resolution drives the positive affective priming effect, then we should not find a positive priming effect in the control experiment.

In Experiment 4, we aimed at replicating the results of Experiment 2 and extending it to a four-colour Stroop task. Participants had to indicate the ink colour of congruent (e.g., ‘RED’ in red ink) and incongruent (e.g., ‘RED’ in blue ink) Stroop primes before making an affective judgement. As in Experiment 2, we predicted positive affective priming after responding to incongruent primes relative to congruent primes, thereby demonstrating how this effect is not specific to the flanker task alone. Moreover, by using an adapted version of the Stroop task (see also De Houwer, 2003; Schouppe et al., 2012; Van Veen & Carter, 2005), we could investigate to what extent the positive affective priming effect is specific to different types of conflict.

EXPERIMENT 1

Method

Participants

Twenty right-handed students (18-23 years old; 2 men) at Ghent University initially participated in the study. Due to a misunderstanding of the response mapping instructions (as indicated by an error rate of more than 45%), the data of seven participants (18-20 years old; all women) were removed from the analyses. These systematic misunderstandings of the response mapping are most probably due to the lack of a training phase. Moreover, there was no online feedback; therefore participants were not aware of using an incorrect response mapping. To ensure a correctly balanced design, 7 additional participants (18-21 years old; 1 men) were tested. All participants provided written informed consent and were paid or received course credits in return for participation.

Stimuli

The primes were flanker stimuli consisting of a vertical array of five arrows. The direction of the central arrow could either match (congruent prime) or mismatch (incongruent prime) the direction of the neighbouring arrows. Target stimuli (see Appendix, or Aarts, De Houwer, & Pourtois, 2012) were positive and negative words, selected on the basis of a normative study involving affective ratings of 700 Dutch words (Hermans & De Houwer, 1994).

Procedure

Participants were told that their main task was to evaluate the valence of words that were preceded by flanker stimuli. Each trial started with a fixation cross for 500 ms, followed by a flanker stimulus for 400 ms, after which the affective word appeared. The affective word remained on the screen until a response was given. The inter-trial interval was 1000 ms (see Figure 1).

The experiment consisted of two experimental blocks of 360 trials, intermixed with self-paced breaks every 90 trials. In each block, each of the 60 words was paired 4 times with a congruent flanker stimulus and 2 times with an incongruent stimulus. This frequency manipulation was adopted to increase the conflict elicited by an incongruent stimulus (Tzelgov, Henik, & Berger, 1992). To ensure that participants were aware of the conflict elicited by the incongruent flanker stimulus, a practice block of 40 trials involving only flanker stimuli (50% congruent, 50% incongruent) preceded each experimental block. In this practice block, a trial started with a fixation cross for 500 ms, after which a flanker stimulus appeared. This stimulus remained on the screen until a response was given or until a response deadline of 1000 ms was exceeded. The inter-trial interval was 1000 ms.

Each task (the flanker task and the affective judgment task) was assigned to a different hand. The task-to-hand mapping was counterbalanced across participants. When performing the affective judgment task with their left hand, participants pressed the ‘D’ key for positive words and the ‘S’ key for negative words. When using their right hand, they pressed the ‘L’ key for positive words and the ‘K’ key for negative words. In the flanker task, participants pressed the ‘E’ or ‘D’ key with their left hand (or ‘I’ or ‘K’ key with their right hand) when the central arrow pointed upwards or downwards respectively.

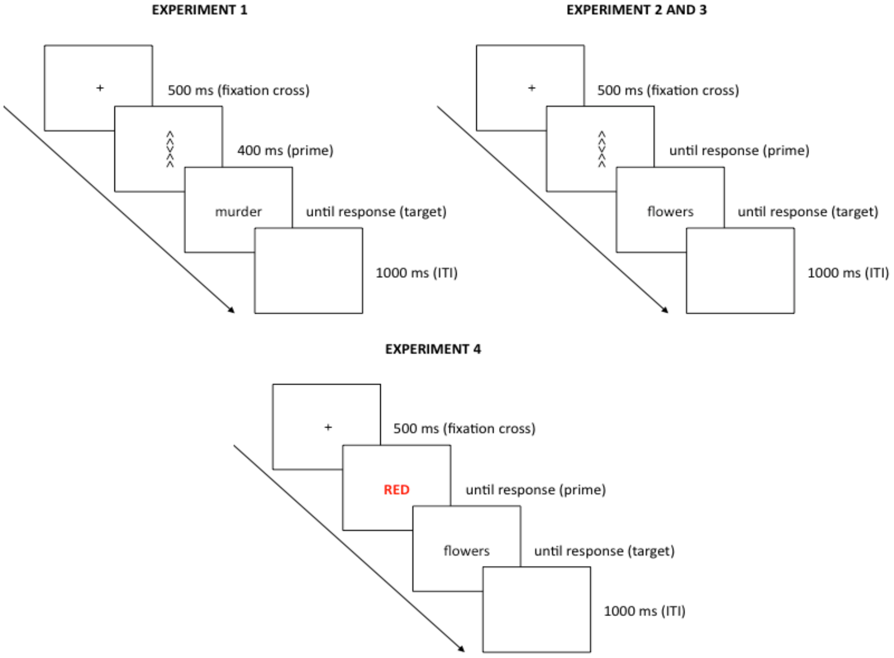

Figure 1. Trial procedure for Experiment 1 (left panel), Experiments 2 and 3 (middle panel) and Experiment 4 (right panel). The only difference between Experiment 2 and Experiment 3 concerns the instructions. In Experiment 2 participants were asked to respond to the direction of the central arrow in the array, in Experiment 3 participants had to determine whether the 5 arrows in the array were similar to each other or not.

Results

Affective Priming Task

Mean RTs and error rates for responses to the target words were analysed using a 2 x 2 repeated-measures ANOVA with prime congruency (congruent vs. incongruent) and target valence (positive vs. negative) as within-subjects factors. The first trial after each break was omitted. Also, trials following an error were excluded to avoid interfering effects of errors on the affective judgement task (Aarts et al., 2012). For the RT analysis, errors (5%) were discarded. Also, trials with responses faster than 200 ms or slower than 2000 ms (< 1%) were excluded. For the error analysis, we used the arc sine square root transformation of the percentage of incorrect responses. This transformation was also used for the following error analyses of Experiment 2-4.

Reaction times. We found a significant interaction between target valence and prime congruency, $F(1, 19) = 4.52$, $p < .05$, $\eta_p^2 = .19$. As depicted in Figure 2, this interaction indicated faster responses on positive targets, relative to negative targets, when preceded by a congruent flanker compared to an incongruent flanker. Paired *t*-tests (two-tailed) did not show a significant difference between congruent and incongruent primes on responses to positive targets, $t(19) = 1.6$, $p > .1$, $\eta_p^2 = .11$, and also not on responses to negative targets, $t(19) = .3$, $p > .1$, $\eta_p^2 = .006$. The main effects of prime congruency and target valence were not significant (all *p*s > .1).

Error rates. In the analysis of the error rates, there was a marginally significant main effect of target valence, $F(1, 19) = 4.0$, $p = .061$, $\eta_p^2 = .173$, and a significant main effect of prime congruency, $F(1, 19) = 7.6$, $p < .05$, $\eta_p^2 = .29$, indicating more errors on positive words and after congruent primes respectively. The interaction effect was not significant, $F(1, 19) < 1$, $\eta_p^2 = .008$

Discussion

Using a similar procedure as Dreisbach and Fischer (2012), we replicated the main finding of an interaction between prime congruency and target valence. Although the effects are relatively small (neither of the pairwise *t*-tests reached significance), the interaction indicates affective priming in the sense that congruent stimuli (relative to incongruent stimuli) prime responses to positive targets.

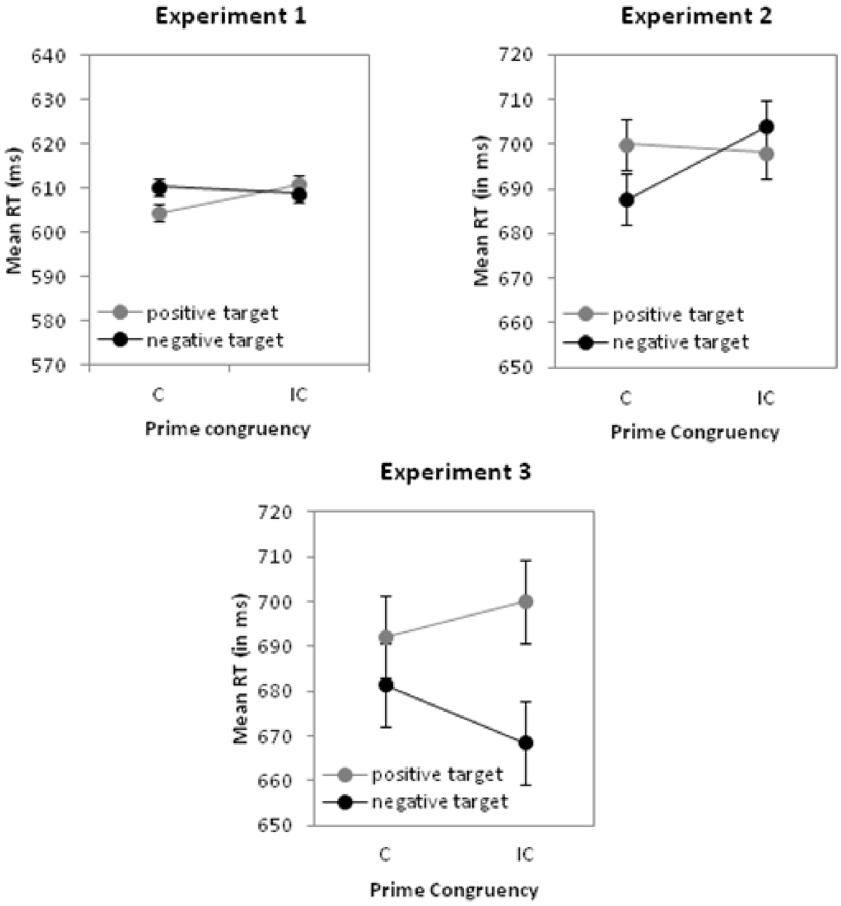

Figure 2. Mean reaction times (RT) for negative and positive word judgements after congruent and incongruent primes. The left panel of the figure demonstrates that congruent stimuli are preferred over incongruent stimuli when there is no response to these stimuli required (Experiment 1). When participants successfully resolved the conflict elicited by the prime stimuli, a preference for the incongruent stimuli was shown (Experiment 2). No preference emerged when participants correctly responded to the prime stimuli, but did not experience conflict (Experiment 3). Error bars are based on the mean square error of the interaction term (Loftus & Masson, 1994).

EXPERIMENT 2

In Experiment 2, we tested whether a different affective priming pattern would emerge when participants successfully responded to the prime stimuli by indicating the direction of the central arrow. However, besides conflict resolution, an additional difference between Experiment 1 and 2 is the prime-to-target interval. Whereas it is constant across conditions in Experiment 1, it is systematically larger for the incongruent condition compared to the congruent condition in Experiment 2 (i.e., congruency effect on prime responses). To counter an explanation in terms of varying prime-to-target intervals, we analyzed the data with prime RT (50% fastest vs. 50% slowest responses) as an additional factor in the design. If the prime-to-target interval drives the priming effect, rather than prime congruency, we would expect an interaction between prime RT and valence where relatively fast prime RTs (whether congruent or incongruent) would have to produce negative priming.

Method

Participants

Twenty right-handed students (18-26 years old; 3 men) at Ghent University participated in Experiment 2. Due to a misunderstanding of the instructions (as indicated by an error rate of more than 45%), the data of three participants (18-21 years old; 1 men) could not be used for analyses. To ensure a correctly balanced design, three additional participants (18-21 years old; all women) were tested. All participants provided written informed consent and were paid or received course credits in return for their participation.

Procedure

Stimuli and trial procedure of Experiment 2 were identical to Experiment 1, except that participants first responded to the direction of the central arrow of the prime stimulus within a 1000 ms response deadline, before performing the affective judgment task (see Figure 1). The same response keys were used as in Experiment 1. The response to the prime stimuli and the response to the target stimuli were assigned to different hands. This task-to-hand mapping was counterbalanced across participants.

Two experimental blocks of 360 trials were administered. The same frequency of congruency manipulation as in Experiment 1 was adopted. To ensure that participants understood the double task instructions, they could first familiarise themselves with the experiment in a practice block of 24 trials. None of the target words used for these practice trials occurred in the experimental blocks.

Results

Prime Task

Practice trials, first trials after each break and trials with RTs shorter than 200 ms were excluded. For the RT analysis, erroneous responses were discarded. RTs were faster on congruent trials (541 ms) compared to incongruent trials (643 ms), thus revealing a significant congruency effect of 102 ms, $t(19) = 11.9$, $p < .001$, $\eta_p^2 = .88$. Overall, mean accuracies were 94%. The error rates also demonstrated a significant congruency effect of 4.2% (5.4% on incongruent trials vs. 1.2% on congruent trials), $t(19) = 5.8$, $p < .001$, $\eta_p^2 = .64$.

Affective Priming Task

Mean RTs and error rates for responses on the target words were analysed using a 2 x 2 x 2 repeated-measures ANOVA with prime congruency (congruent vs. incongruent), target valence (positive vs. negative) and prime RT (50% fastest vs. 50% slowest prime responses; based on a median split on prime RTs for each congruency condition separately) as within-subjects factors. Practice trials, the first trial after each break and the first trial following an erroneous response were excluded. For the RT analysis, errors (9% target errors and 6% prime errors) were also discarded. Also, trials faster than 200 ms or slower than 2000 ms (2%) were excluded.

Reaction times. Target RTs showed a main effect of prime RT, $F(1, 19) = 65.8$, $p < .001$, $\eta_p^2 = .78$. Targets preceded by a fast prime response were responded to faster than targets preceded by a slow prime response. Also a marginally significant interaction between prime congruency and prime RT was found, $F(1, 19) = 4.4$, $p = .050$, $\eta_p^2 = .19$, indicating a larger effect of prime congruency on target RTs when the target was preceded by a fast prime response compared to a slow prime response. Most importantly, the interaction between target valence and prime congruency was significant, $F(1, 19) = 5.1$, $p < .05$, $\eta_p^2 = .21$, demonstrating that participants responded faster on negative targets, relative to positive targets, when preceded by a congruent flanker compared to an incongruent flanker (see also Figure 2). No other main and interaction effects were significant (all *p*s > .1). Crucially, the interaction between target valence and prime RT was not significant, $F(1, 19) = 1.3$, $p > .1$, suggesting that variability in prime-to-target interval did not influence responses to positive and negative targets. Moreover, the interaction between target valence, prime congruency and prime RT was not significant, $F(1, 19) < 1$, indicating that the prime-to-target interval did not modulate the obtained affective priming effect.

We zoomed further into the significant affective priming effect by means of paired *t*-tests (two-tailed). The results showed that negative words were faster responded to when preceded by a congruent prime than by an incongruent prime, $t(19) = 2.6$, $p < .05$, $\eta_p^2 = .26$. The nature of the prime did not influence responding to positive words, $t(19) = 0.4$, $p > .1$, $\eta_p^2 = .009$.

The affective priming effect is exactly the reserve pattern as observed in Experiment 1 and Dreisbach and Fischer’s study (2012). This is also demonstrated by the 2 (prime congruency: congruent vs. incongruent) x 2 (target valence: positive vs. negative) x 2 (experiment: 1 vs. 2) repeated-measures ANOVA on mean RTs, showing a significant three-way interaction between target valence, prime congruency and experiment, $F(1, 38) = 8.9$, $p < .01$, $\eta_p^2 = .19$.

Error rates. The error rates showed a main effect of target valence, $F(1, 19) = 4.8$, $p < .05$, $\eta_p^2 = .20$, indicating more errors on trials with positive targets compared to trials with negative targets. All other main and interaction effects were not significant, all *p*s > .1.

Discussion

The results of Experiment 2 showed that correctly responding to incongruent trials is evaluated more positive than correctly responding to congruent trials. As there was a congruency effect of 102 ms in prime RTs, the average prime-target interval was approximately 100 ms shorter for congruent trials. However, the binary factor prime RT (with fast and slow prime trials that were separated on average 154 ms apart) did not show an influence on the priming effect, yielding an explanation in terms of different prime-target intervals unlikely.

EXPERIMENT 3

As predicted, we observed positive affective priming after incongruent primes in Experiment 2, thereby contrasting the results of Experiment 1 and of Dreisbach and Fischer (2012). However, to further investigate whether the positive affective priming effect is due to resolving the conflict induced by incongruent primes, we conducted a control experiment that was identical to Experiment 2, except that participants now responded on the basis of the similarity of the direction of the central and flanker arrows. We can expect that participants are faster to determine that all arrows point in the same direction than to determine that the central and flanker arrows point in a different direction (i.e., similarity judgement effect, Nickerson, 1965). Therefore, the stimuli still vary in task difficulty, but no longer induce conflict. Hence, determining whether arrows point in a different direction does not require conflict resolution. If the positive affective priming effect after incongruent primes in Experiment 2 is caused by conflict resolution, we should not observe positive priming in Experiment 3. However, when the positive priming is caused by correctly responding to a more difficult stimulus, as predicted by the model of Silvetti et al. (2011), we should observe a similar positive priming effect for ‘different’ responses.

Method

Participants

Twenty right-handed students (18-25 years old; 6 men) at Ghent University initially participated. Due to a misunderstanding of the instructions (as indicated by an error rate of more than 45%), the data of three participants could not be used for analyses (18-21 years old; all women). To ensure a correctly balanced design, three additional participants (18-24 years old, 1 men) were tested. All participants provided written informed consent and were paid or received course credits in return for their participation.

Procedure

Experiment 3 was identical to Experiment 2, except that participants were instructed to determine whether all the arrows in the array pointed in the same direction or not. In Experiment 2 the key assignment of the flanker task (e.g., ‘up’ and ‘down’ responses) was kept constant. In Experiment 3 however, the key-to-response mapping (same vs. different) of the similarity judgment task was also counterbalanced.

Furthermore, in order to ensure that participants in Experiment 3 were aware of the fact that some prime stimuli induced conflict whereas others did not, they also completed a block of 40 trials with only flanker stimuli (50% congruent, 50% incongruent) immediately before each experimental block. In this flanker block, a trial started with the presentation of a fixation cross for 500 ms, after which a flanker stimulus appeared. This stimulus remained on the screen until a response was given or until a response deadline of 1000 ms was exceeded. The inter-trial interval was 1000 ms.

Results

Prime Task

Practice trials, first trials after each break and trials with RTs shorter than 200 ms were excluded. For the RT analyses, erroneous responses were also discarded. Overall, mean accuracy for the prime task was 92%. Results revealed a significant similarity effect, both in RTs (65 ms), $t(19) = 11.3$, $p < .001$, $\eta_p^2 = .87$, and error rates (1.9%), $t(19) = 2.7$, $p < .05$, $\eta_p^2 = .28$, with faster and more accurate responses for same responses (554 ms; 3.8%), compared to different responses (619 ms; 5.7%).

Affective Priming Task

Mean RTs and error rates for responses on the target words were analysed using a 2 x 2 x 2 repeated-measures ANOVA with prime congruency (congruent vs. incongruent), target valence (positive vs. negative) and prime RT (50% fastest vs. 50% slowest) as within-subjects factors. Practice trials, the first trial after each break and the first trial following an erroneous response were excluded. For the RT analyses, errors (9% target errors and 8% prime errors) were also discarded. Also, trials faster than 200 ms or slower than 2000 ms (2%) were excluded.

RTs and error rates showed a main effect of target valence, however, the direction of this effect was opposite to what is typically found in affective priming studies. More specifically, we observed faster, $F(1, 19) = 7.5$, $p < .05$, $\eta_p^2 = .28$, and more accurate, $F(1, 19) = 6.1$, $p < .05$, $\eta_p^2 = .24$, responses to negative targets than to positive targets. RTs also showed a main effect of prime RT, $F(1, 19) = 30.3$, $p < .001$, $\eta_p^2 = .62$, indicating that a fast prime response is followed by a fast target response. Furthermore, a marginally significant main effect of congruency was present in the error rates, $F(1, 19) = 3.0$, $p = .098$, $\eta_p^2 = .14$. All other main and interaction effects in the RT and error rate analyses did not reach significance (all *p*s > .1).

Importantly, when comparing Experiment 2 to Experiment 3 we found a significant three-way interaction between prime congruency, target valence and experiment on mean RTs, $F(1, 38) = 4.4$, $p < .05$, $\eta_p^2 = .10$ (see also Figure 2), indicating that conflict resolution, rather than acting upon a difficult trial is critical for the positive priming effect obtained in Experiment 2. Furthermore, this control experiment also provides us with an extra test whether the different prime-to-target intervals between congruent and incongruent conditions drive the positive affective priming effect in Experiment 2, compared to Experiment 1. An affective priming effect similar to Experiment 1 would provide additional evidence that the prime-to-target interval is not critical in obtaining the reversed priming effect in Experiment 2. This was confirmed by the non-significant interaction between prime congruency, target valence and experiment (1 vs. 3), $F < 1$.

Discussion

The results of Experiment 3 did not show a significant affective priming effect, indicating that correctly responding to difficult trials, relative to easy trials, did not prime responses to positive targets. This suggests that conflict resolution is crucial for bringing about the positive affective priming effect of Experiment 2.

EXPERIMENT 4

We replicated the original observation of Dreisbach and Fischer (2012) in a flanker task, showing how incongruent stimuli can induce a negative affective priming effect (Experiment 1), suggesting that cognitive conflict is aversive. In Experiment 2, we demonstrated that this effect turns into a positive affective priming effect when subjects respond to the prime stimuli. This effect turned out to be specific to conflict resolution (Experiment 3). In this final experiment, we aimed at replicating the positive affective priming effect after conflict resolution, using a four-colour Stroop task. By testing our hypothesis in a Stroop task, we were able to directly link back to the original observation of Dreisbach and Fischer (2012), who showed a negative affective priming effect after merely observing incongruent Stroop primes, compared to congruent Stroop primes. A reversal of this priming effect after responding to the Stroop primes would validate our conclusion that conflict resolution results in positive affect. Moreover, by mapping four colours to two responses we could distinguish between (1) congruent (CO) trials, in which the colour and the meaning of the word matched, (2) stimulus incongruent (SI) trials, in which the colour and the meaning of the word mismatched, but activated the same response, and (3) response incongruent (RI) trials, in which the colour and the meaning of the word mismatched, and also activated a different response. SI and RI trials have been demonstrated to have dissociable effects on behaviour (e.g., Notebaert & Verguts, 2006; Schouppe et al., 2012) and brain activity (e.g., Van Veen & Carter, 2005). However, we believe both can have a similar effect on our affective priming task, since both types induce a cognitive conflict that needs to be resolved for efficient task performance.

Method

Participants

Thirty-two right-handed students (17-31 years old; 6 men) at Ghent University initially participated. Due to a misunderstanding of the instructions (as indicated by an error rate of more than 45%), the data of four participants could not be used for analyses (18-19 years old; 1 men). To ensure a correctly balanced design, four additional participants (18-19 years old, 1 men) were tested. All participants provided written informed consent and were paid or received course credits in return for their participation.

Stimuli

Prime stimuli now consisted of the Dutch words ‘BLAUW’, ‘GROEN’, ‘ROOD’, or ‘GEEL’ (meaning blue, green, red, or yellow), presented in uppercase letters in a blue, green, red, or yellow font colour. Target stimuli were the same as in the preceding experiments.

Procedure

Experiment 4 was similar to Experiment 2, except that the prime conflict task was now a four-colour Stroop task, instead of an arrow flanker task. In a Stroop task, participants are instructed to respond to the ink colour of a word, while ignoring its meaning. We used a Stroop task where four colours were mapped onto two responses (see De Houwer, 2003; Schouppe et al., 2012; Van Veen & Carter, 2005). For example, in one response mapping, participants were instructed to press the upper button when the ink colour was red or yellow, and the lower button when the colour was blue or green (stimuli-set to button assignment was counterbalanced across participants). In this way, we can create SI and RI stimuli. The former are stimuli where the ink colour differs from the colour word, but both colours are associated with the same response (e.g., the word ‘RED’ in yellow ink). In the latter, ink colour again differs from the colour word, but now both colours are associated with a different response (e.g., the word ‘RED’ in blue). One third of the trials were SI trials, another third of the trials were RI trials and a last third of the trials were CO trials, where the ink colour of the word corresponded to its meaning (e.g., ‘RED’ in red). To keep the possible stimulus combinations (combining stimulus colour and word meaning) constant across conditions (four per congruency type), only a subset of the eight possible RI stimuli was used. This subset was counterbalanced across participants. The trial procedure was identical to Experiment 2, except that participants now first responded to the ink colour with no response deadline, before performing the affective judgment task. The same response keys were used as in the preceding experiments. The response to the prime stimuli and the response to the target stimuli were assigned to different hands. This task-to-hand mapping was also counterbalanced across participants. Altogether, each participant was randomly assigned to one of the eight versions of this experiment (counterbalancing stimuli-set to button assignment, task-to-hand mapping, and subset RI stimuli).

Two experimental blocks of 360 trials were administered, intermixed with self-paced breaks every 90 trials. To ensure that participants understood the double task instructions, they could first familiarise themselves with the experiment in a practice block of 24 trials. None of the target words used for these practice trials occurred in the experimental blocks.

Results

Prime Task

Practice trials, first trials after each break and trials with RTs shorter than 200 ms were excluded. For the RT analyses, erroneous responses were also discarded. RTs showed an increase from CO trials to SI trials to RI trials. CO trials (736.5 ms) were significantly faster than SI trials (765.3 ms), $t(31) = 4.6$, $p < .001$, $\eta_p^2 = .41$ and RI trials (810.7 ms), $t(31) = 7.3$, $p < .001$, $\eta_p^2 = .63$. Moreover, RTs on SI trials were significantly faster than on RI trials, $t(31) = 4.7$, $p < .001$, $\eta_p^2 = .42$. Overall, mean accuracy for the prime task was 96%. More errors were made on RI trials (5.3%), compared to CO trials (3.4%), $t(31) = 3.9$, $p < .001$, $\eta_p^2 = .33$, and SI trials (2.8%), $t(31) = 5.1$, $p < .001$, $\eta_p^2 = .46$. Error rates did not differ significantly between CO and SI trials, $t(31) = 1.1$, $p > .1$, $\eta_p^2 = .04$.

Affective Priming Task

Mean RTs and error rates for responses on the target words were analysed using a 3 x 2 x 2 repeated-measures ANOVA with prime congruency (CO, SI, RI), target valence (positive vs. negative) and prime RT (50% slowest vs. 50% fastest) as within-subjects factors. Practice trials, the first trial after each break and the first trial following an erroneous response were excluded. For the RT analyses, errors (7% target errors and 4% prime errors) were also discarded. Also, trials faster than 200 ms and slower than 2000 ms (1%) were excluded. Greenhouse-Geisser corrections to the *p*-values are used when the sphericity assumption was violated, but uncorrected degrees of freedom are reported for ease of reading.

Reaction times. RTs showed a main effect of prime RT, $F(1, 31) = 164.2$, $p < .001$, $\eta_p^2 = .84$, and a main effect of prime congruency, $F(2, 62) = 14.2$, $p < .001$, $\eta_p^2 = .31$. Furthermore, the interaction between target valence and prime congruency was significant, $F(2, 62) = 3.3$, $p < .05$, $\eta_p^2 = .10$ (see Figure 3). All other main and interaction effects were not significant (all *p*s

> .1). Importantly, neither the interaction between prime RT and target valence, $F(2, 62) < 1$, nor the interaction between prime RT, target valence and prime congruency were significant, $F(2, 62) = 2.1$, $p > .1$.

The significant target valence x prime congruency interaction was further investigated using contrast analyses. Firstly, there was no priming effect for RI over SI trials, $F(1, 31) < 1$. Secondly, a positive priming effect for SI primes over CO primes was shown, $F(1, 31) = 6.6$, $p < .05$, $\eta_p^2 = .18$. Paired *t*-tests (two-tailed) on this CO-SI priming effect showed that negative words were responded to faster when preceded by a CO prime than by a SI prime, $t(19) = 3.0$, $p < .01$, $\eta_p^2 = .22$, with no difference between the two prime conditions on positive words, $t(19) < 1$. Lastly, there was a positive affective priming effect for RI primes over CO primes, $F(1, 31) = 4.6$, $p < .05$, $\eta_p^2 = .13$. Looking into this CO-RI priming effect, results showed faster responses on negative targets when preceded by CO trials compared to RI trials, $t(19) = 5.0$, $p < .001$, $\eta_p^2 = .448$, as well as faster responses on positive targets when preceded by CO trials compared to RI trials, $t(19) = 3.2$, $p < .01$, $\eta_p^2 = .25$, yet the RT difference between prime conditions on positive targets is smaller than the difference between prime conditions on negative targets, thereby causing the positive affective priming effect.

Error rates. There were no significant main or interaction effects found in the error rates, all *p*s > .1.

Discussion

Using an affective priming procedure where Stroop stimuli served as primes, Dreisbach and Fischer (2012) recently demonstrated the negative nature of incongruent stimuli. In Experiment 4, we used a similar procedure as Dreisbach and Fischer, with the only exception that participants were first asked to respond to the Stroop stimuli before making an affective judgement. Our results showed a reversed affective priming effect, thereby replicating the results of Experiment 2 and confirming our conclusion that conflict resolution is associated with positive affect. Moreover, we showed that resolving both stimulus and response conflict induced this affective state.

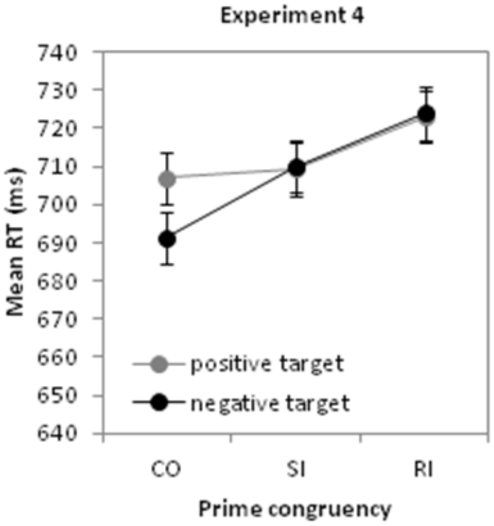

Figure 3. Mean reaction times (RT) for negative and positive word judgements after CO, SI and RI primes. Error bars are based on the mean square error of the interaction term (Loftus & Masson, 1994).

GENERAL DISCUSSION

The hypothesis that conflict is aversive (Botvinick, 2007) has spurred a great deal of research. Whereas previous studies suggested that incongruent stimuli are affectively negative (Brouillet et al., 2011; Cannon et al., 2010; Dreisbach & Fischer, 2012; Lynn et al., 2012; Schouppe et al., 2012; van Steenbergen et al., 2009, 2010), our results suggest that conflict resolution results in positive affect. Specifically, in Experiment 2 and 4 we found a positive affective priming effect after *responding* to incongruent primes, relative to *responding* to congruent primes. Furthermore, we did not find a similar positive evaluation in a control experiment in which participants also had to respond to the prime stimuli but did not need to resolve conflict, suggesting that conflict resolution is crucial.

Our observed positive affective priming effect, induced by responding to incongruent trials, is consistent with the findings of Molapour and Morsella (2010) who demonstrated that participants expressed more liking towards nonsense shapes, when these shapes co-occurred with responding to incongruent, but not with responding to congruent or neutral Stroop stimuli. Their effect, as well as ours, could reflect a positive prediction error signal, following the initial outcome expectancy, that is lower for incongruent, than congruent stimuli (Silvetti et al., 2011). Our findings also concur with the recent interest of an affective dimension in cognitive tasks: whereas earlier research implied a strict division between cognitive and affective processing in ACC (Bush, Luu, & Posner, 2000), more extensive analyses demonstrated that affect (e.g., pain) related and conflict related brain areas overlap considerably (Shackman et al., 2011). In line with our conclusions on the positive aspect of conflict resolution, other studies have argued that relief from pain can also have a rewarding effect (Tanimoto, Heisenberg, & Gerber, 2004). For instance, Leknes, Lee, Berna, Andersson, and Tracey (2011) showed an activation overlap in ventromedial prefrontal cortex and rostral ACC during an appetitive reward task and a relief from pain task.

On the basis of Silvetti et al. (2011), we predicted a positive priming effect after successfully responding to incongruent primes. In this computational model, incongruent stimuli have worse performance characteristics than congruent trials both in terms of RT and accuracy, which can explain the negative priming effect in Experiment 1. After a correct response, a positive prediction error (doing better than expected) occurs which could cause the positive priming effect. Our control experiment, however, showed a similarity effect on the prime responses, both in reaction times and in error rates, indicating that ‘different’ trials also had worse performance characteristics than ‘same’ trials. Consequently, the model would also predict a positive prediction error (and positive priming) after successfully responding to ‘different’ trials.

The fact that this is not observed suggests that the positive affect is specifically associated with resolving conflict and did not merely result from correctly responding to a more difficult trial. An incongruent trial differs qualitatively from a congruent trial in that the processing of irrelevant conflicting stimulus features need to be overridden in order to efficiently respond to the relevant task feature. This idea that mean RT and accuracy do not fully characterize conflict processing was also recently demonstrated by Hughes and Yeung (2011). They used two versions of the flanker task (conflict and masked), which were matched in RT and accuracy, but elicited different neurophysiological correlates of conflict. In their masked version of the flanker task, incongruent trials were replaced by masked congruent trials. Although these trials were harder to discriminate (equally difficult as incongruent stimuli), they did not induce conflict, as evidenced by lateralised motor activity.

Besides task difficulty, we also wanted to differentiate between stimulus and response incongruency (Experiment 4). Some studies have highlighted the dissociable effects of both congruency types on behaviour (e.g., Notebaert & Verguts, 2006; Schouppe et al., 2012) and brain activity (e.g., Van Veen & Carter, 2005). However, recent electrophysiological studies demonstrated how ACC activity, induced by SI or RI trials, does not dissociate between both trial types (Nigbur, Cohen, Ridderinkhof, & Stürmer, 2012; Wendt, Heldmann, Münte, & Kluwe, 2007). Therefore, in line with the RVPM of ACC activity, we hypothesized that the conflict-induced positive affective priming effect should not depend on conflict type (stimulus or response conflict). Our results are in line with this hypothesis and hence further support generalized detection and resolution of stimulus or response conflict.

In both Experiments 2 and 4, the interaction between prime congruency and target valence manifested as a faster processing of negative targets after congruent compared to incongruent primes (SI or RI). However, the results of Experiment 2 and 4 do not warrant the inference that congruent primes facilitate the evaluation of negative targets. For example, it is also plausible that a main effect of valence (as was observed in Experiment 3) is being countered after incongruent primes, suggesting that the affective priming effect in Experiment 2 and 4 is the result of incongruent primes facilitating responses to positive targets. One possibility to verify this in future research could be the inclusion of neutral primes.

Using an affective priming paradigm, we demonstrated how responding to incongruent trials is associated with positive affect. However, at first sight, other experiments that resemble our setup may seem to contrast our results. Specifically, Brouillet et al. (2011) and Cannon et al. (2010) concluded that responding to compatible prime stimuli results in positive, rather than negative, affect. However, instead of the simultaneous assessment in Brouillet et al. (2011) and Cannon et al. (2010), our affect measurement occurred after conflict resolution. Therefore, we suggest that in these previous studies conflict and its associated negative affect is still experienced during the affect measurement. Additionally, the studies of Brouillet et al. (2011) and Cannon et al. (2010) used a different type of conflict, investigating the affective nature of responses to grasp-compatible versus grasp-incompatible objects. According to the taxonomy of Kornblum, Hasbroucq, and Osman (1990; see also Egner, 2008), the conflict in these tasks originates from a dimensional overlap between an irrelevant stimulus dimension and the response dimension. A recent study of Kerzel and Buetti (2012) indeed suggested that conflict of this type leaks into the movement execution, because of continuing response conflict. We argue that response conflict in the studies of Brouillet et al. (2011) and Cannon et al. (2010) is still experienced at the time of responding, explaining positive affect on compatible responses. In contrast, our flanker and Stroop conflict is induced by a dimensional overlap between an irrelevant and relevant stimulus dimension, suggesting that conflict mainly occurred before the response.

Our results have important implications for theories of cognitive control. Until now, these theories have focused mainly on the aversive nature of cognitive conflict. For example, it has been argued that this negative valence may drive adaptations to conflict (Botvinick, 2007). Consistently, van Steenbergen et al. (2009, 2010) found that conflict adaptation disappears in a state of positive mood (but see Kunde, Augst, & Kleinsorge, 2012 who failed to find such effects). They argued that a positive mood counteracts the negative valence of conflict and thus eliminates adaptation after conflict. These findings are in line with other theories postulating that positive mood increases task distractibility (Dreisbach & Goschke, 2004; Dreisbach, 2006) and suggest that cognitive control is mainly driven by aversive task demands.

However, our findings shed a new light on this issue. In contrast to Botvinick (2007) and van Steenbergen et al. (2009, 2010), we suggest that conflict adaptation may as well be caused by the intrinsic positive evaluation that occurs after responding to incongruent stimuli. The rewarding value of resolving an incongruent stimulus may motivate a person to enhance the task focus that drove him/her to that response. Computationally, this would mean that task-relevant associations are strengthened after (intrinsic) reward experience (for instance, as implemented in the adaptation by binding model, Verguts & Notebaert, 2008, 2009). It would imply that conflict resolution, rather than conflict itself, triggers adaptations. This idea is in line with the observation that cognitive conflict and errors trigger different adaptations (Notebaert & Verguts, 2011; Stürmer, Nigbur, Schacht, & Sommer, 2011) and the observation that conflict adaptation was increased after performance-related reward, and disappeared after reward omission (Braem, Verguts, Roggeman, & Notebaert, 2012). Note that our hypothesis does not exclude the idea that cognitive adaptations are driven by the aversiveness of conflict. However, we suggest that this may occur more indirectly than originally thought: the intrinsic positive evaluation triggered by resolving the (aversive) cognitive conflict can be what motivates us in adapting our strategy.

In sum, we demonstrated that conflict resolution can have a positive connotation. This positive affect is not observed when participants are not required to resolve conflict. These findings have important implications for the current theorizing on the role of cognitive conflict in cognitive control and suggest that theories should include this potential rewarding role in explaining task (e.g., trial-to-trial) adaptations.

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APPENDIX

Table 1. Target words selected from the Dutch affective rating list of Hermans and De Houwer (1994)

Positive targets		*Negative targets*	
applaus (applause)	lente (spring)	aids (aids)	ongezond (unhealthy)
baby (baby)	leven (life)	brutaal (impudent)	oorlog (war)
bloemen (flowers)	liefde (love)	dief (thief)	pijn (pain)
bruid (bride)	melodie (melody)	dood (dead)	puist (pustule)
cadeau (present)	omhelzing (embrace)	drugs (drugs)	ruw (rude)
droom (dream)	oprecht (sincere)	geweren (guns)	sluw (sly)
Engel (angel)	parfum (perfume)	graf (tomb)	spin (spider)
feest (party)	regenboog (rainbow)	haat (hate)	stank (stench)
geboorte (birth)	romantiek (romanticism)	hatelijk (hateful)	vals (false)
geschenk (gift)	spel (game)	hitler (hitler)	vijandig (hostile)
goud (gold)	trots (proud)	hoer (whore)	virus (virus)
Hawaii (Hawaii)	trouw (fidelity)	kanker (cancer)	vuil (dirty)
hemel (heaven)	vakantie (holiday)	koud (cold)	vulgair (vulgar)
humor (humor)	vrede (peace)	moord (murder)	zwak (weak)
knuffel (hug)	zomer (summer)	ongeval (accident)	zweer (sore)

CHAPTER 7

AFFECTIVE MODULATION OF COGNITIVE CONTROL IS DETERMINED BY PERFORMANCE-CONTINGENCY[1]

Cognitive control requires a fine balance between stability, the protection of an on-going task-set, and flexibility, the ability to update a task-set in line with changing contingencies. It is thought that emotional processing modulates this balance, but results have been equivocal regarding the direction of this modulation. Here, we tested the hypothesis that a key mediating factor in this modulation is whether affective stimuli are introduced as performance-contingent or as task-irrelevant signals. Combining functional magnetic resonance imaging (fMRI) with a conflict task-switching paradigm, we contrasted the effects of presenting negative- and positive-valence pictures on the stability/flexibility trade-off, depending on whether picture presentation was contingent on behavioural performance. Both the behavioural and neural expressions of cognitive control were modulated by stimulus valence and performance-contingency: As predicted, in the performance-contingent condition, cognitive flexibility was enhanced following positive pictures, whereas in the non-performance-contingent condition, positive stimuli promoted cognitive stability. Moreover, while the stability/flexibility trade-off was reflected in a differential recruitment of doroslateral frontopariatal and striatal regions, its affective modulation was mirrored by neural responses in the ventromedial prefrontal and posterior cingulate cortices, whose activity reflected the degree of behaviour flexibility, as modulated by affect and performance-contingency.

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[1] Braem, S., King, J. A., Korb, F. M., Krebs, R. M., Notebaert, W., & Egner, T. (submitted). Affective modulation of cognitive control is determined by performance-contingency and mediated by cingulate cortex.

INTRODUCTION

Successful navigation through our environment requires the ability to focus on the current task while simultaneously being capable of switching to a more urgent task or respond to unexpected events. This optimal balancing between stability (exploitation) and flexibility (exploration) plays a fundamental role in our daily decision-making (Cohen, McClure, & Yu, 2007; Gittins & Jones, 1974) and anomalies in this balance are central to various clinical disorders (Frank, Doll, Oas-Terpstra, & Moreno, 2009; Strauss et al., 2011). It is widely thought that affective processes modulate this stability/flexibility trade-off (Easterbrook, 1959; Isen, 2000). However, the nature of this modulation is presently equivocal.

One attractive hypothesis for the affective modulation of cognitive stability/flexibility is based on the idea that positive (negative) stimuli increase (decrease) dopamine release, which facilitates (suppresses) the gating of new information into prefrontal working memory or task-set representations (Ashby, Isen & Turken, 1999; Braver & Cohen, 2000). While some studies have supported this idea (van Steenbergen, Band, & Hommel, 2009, 2012), others have produced contradictory results (Gable & Harmon-Jones, 2008; Padmala, Bauer, & Pessoa, 2011). Here, we tested the hypothesis that performance-contingency is a key factor in determining the exact nature of these emotion-cognition interactions.

Specifically, we predicted that performance-contingent positive affect signals that task goals are being met successfully, loosening task focus toward a more exploratory mode (Carver, 2003; Gable & Harmon-Jones, 2011, van Steenbergen et al., 2009), while performance-contingent negative affect promotes the need for stabilizing the present task-set, directing attention towards the task (van Steenbergen et al., 2012). By contrast, Gable and Harmon-Jones (2008) demonstrated how presenting non-contingent positive pictures can speed local (relative to global) target detection, arguing that positive pictures rouse an “approach motivation”, inducing a narrower (exploitation) task focus, while non-contingent negative pictures have been argued to shift attention away from the task (Padmala et al., 2011). We tested these predictions by presenting negative or positive pictures following trials of a task-switching experiment that employed bivalent stimuli, which could be either congruent or incongruent (i.e., conflict-inducing). Importantly, the presentation of the affective stimuli was either performance-contingent, or not. We tested this manipulation on a single, direct metric of the stability/flexibility trade-off, namely the conflict-modulated task-switch cost (“Goschke effect”), referring to a larger switch cost following incongruent trials than following congruent trials (Goschke, 2000). This effect is thought to reflect the detrimental impact of conflict-induced enhancement of task-focus (i.e., increased stability, Botvinick, Braver, Barch, Carter, & Cohen, 2001) on the cognitive flexibility required for a task-switch. Thus, a smaller (larger) Goschke effect reflects more flexibility (stability).

Moreover, because neuroscience models of affective modulation of cognitive control (Ashby, Isen, & Turken, 1999; Gray, 2001; Pessoa, 2008, 2009; Shackman et al. 2011) have not previously considered the exact role of performance-contingency (Chiew & Braver, 2011), the neural substrates of these key emotion-cognitive interactions are presently unknown. By pairing our task-switching experiment with functional magnetic resonance imaging (fMRI), we sought to identify the brain regions associated with the Goschke effect and its potential modulation by affect and performance-contingency.

MATERIALS AND METHODS

Participants

Thirty-five participants took part in this study (mean age = 26 years, SD = 6; 17 female). All participants had normal or corrected to normal vision, and were right-handed as assessed by the Edinburgh Handedness Inventory. They gave their informed written consent and reported no current or history of neurological, psychiatric or major medical disorder. Every participant was paid $35 for participating, as well as an extra $16 during the task as part of the experiment's reward schedule (which will be explained below). The work has been completed with the approval of the Duke University Health System Institutional Review Board.

Stimuli

The task stimuli were the numbers 1, 2, 3, 4, 6, 7, 8 or 9, centrally presented in isoluminant green or blue. Fifty positive and fifty negative pictures were selected from the from the International Affective Pictures System (IAPS; Lang, Bradley, & Cuthbert, 2008) data-base, matched on their semantic content (e.g. crying baby vs. smiling baby, cute animal vs. dangerous animal, sunset vs. thunderstorm). All stimuli were presented against a black background on a back-projection screen, which participants viewed in a mirror mounted to the head coil. This setup simulated a viewing distance of 80 cm, resulting in picture sizes of 10° wide and 7.4° high and number stimuli of approximately 0.4° wide and 0.8° high. Responses were registered via a MR-compatible response box (Current Designs), which was placed on the participant's abdomen (oriented perpendicular to the length of their body). The task required the participants to press the left- or rightmost button (out of four horizontally aligned response buttons) with their left or right hand, respectively. Stimuli presentation and response registration were performed using Presentation software (Neurobehavioral Systems).

Procedure

The goal of the study design was to assess the effect of affective stimuli (positive or negative IAPS pictures) on cognitive-control processes involved in switching between conflicting task goals, depending on whether the affective stimuli were tied to task performance or not. To this end, we presented affective picture stimuli (positive vs. negative) tied to monetary gains following each trial of a standard task-switching protocol. Importantly, in one group of subjects ("non-performance-contingent condition”), these affective stimuli were unrelated to performance, whereas in another, closely matched group of subjects (“performance-contingent condition”), affective feedback (and monetary gain) was dependent on performance speed and accuracy. Specifically, participants were informed that task stimuli would be followed by a randomly chosen positive or negative picture and that positive pictures were associated with 10 cents monetary gain. In the non-performance-contingent condition, the instructions explicitly mentioned that the picture presentation was unrelated to task performance. In the performance-contingent condition, participants were informed that there would be no picture presentation (and therefore no chance of gaining money) after incorrect or too slow responses. Finally, response speed and accuracy were stressed in both conditions. Importantly, besides the difference in instructions concerning the pictures, and the absence of pictures after inaccurate or slow responses (exceeding the 1500 ms deadline) in the performance-contingent condition, there were no differences between the two conditions.

The task switching paradigm itself required participants to carry out either a parity or magnitude judgment on the digit stimuli depending on the color in which each digit was presented. Specifically, when the digit was presented in blue, subjects had to press a left-hand button if the number was odd and a right-hand button if the number was even. When the number was presented in green, subjects had to press left if it was smaller than five and right if it was bigger than five. These task-color associations were counterbalanced across participants. A random serial presentation of these stimuli (excluding number repetitions) created task sequences of task repetitions and task switches, allowing us to assess typical task-switch costs. Moreover, because the digit stimuli were bivalent, that is, each stimulus was associated with possible responses in both task-sets, and stimulus categories in the different task-sets were mapped onto overlapping response sets, each stimulus could be either congruent (i.e., it would produce the same manual response in both task-sets) or incongruent (it would render different responses in the two task-sets). Overall, these manipulations produced a factorial mixed-effects design, which we analyzed according to the following 5 factors of interest: the within-subject factors of task sequence (task-repetition vs. task-switch), previous trial congruency (congruent vs. incongruent), current trial congruency (congruent vs. incongruent trial), and the valence of the picture (positive vs. negative) that preceded the current trial (we call this factor “preceding valence” from here onwards); and finally, the between-subjects factor of contingency condition (performance-contingent vs. non-performance-contingent).

As shown in Figure 1A, each trial began with a colored digit stimulus, presented 0.6° above a central fixation dot (which remained on-screen throughout the task) for 200 ms. There was a maximum response time (RT) window of 1500 ms, starting from stimulus onset. Stimulus presentation was followed by a variable stimulus-picture interval. Thereafter, an IAPS picture was presented for 500 ms, which was followed by another variable picture-stimulus interval until the next digit stimulus was presented. Both variable time-intervals were independently randomized and were drawn from a pseudo-exponential distribution (50 % lasted 3 seconds (s), 25 % 3.5 s, 12 % 4 s, 7 % 4.5 s, and 6 % 5 s), resulting in a mean time interval of ~ 3.5 s. This jittering allowed us to estimate independently activations associated with each digit and picture stimulus (e.g., Ollinger, Corbetta, & Shulman, 2001). Importantly, in the performance-contingent condition, the picture did not follow the response if the subjects had not responded correctly or within the response time window. Instead, the fixation dot was presented for 500 ms.

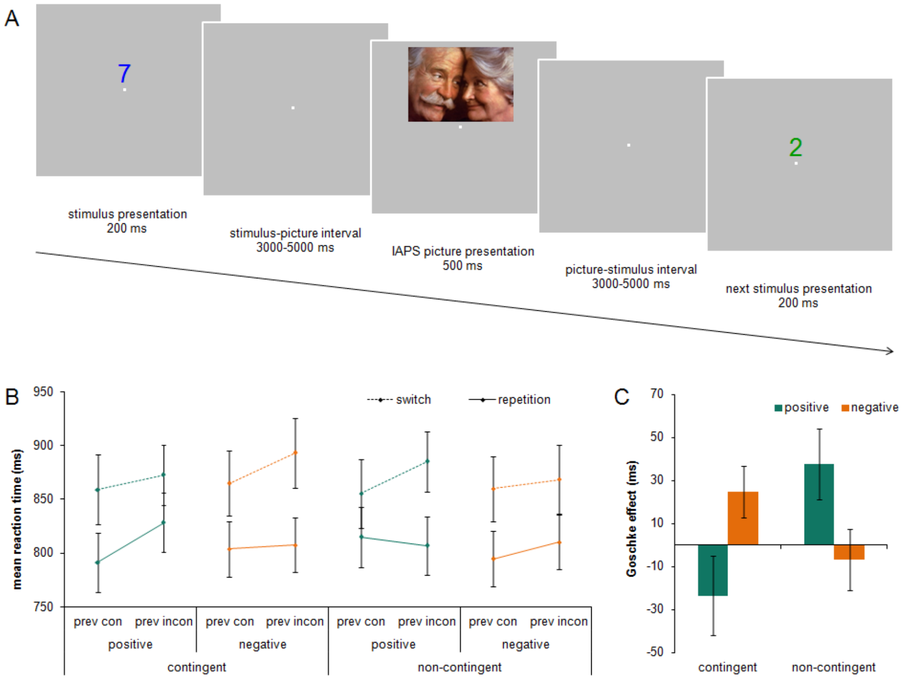


Figure 1. General paradigm and behavioral results. **A.** Trial procedure. Participants had to respond to digit stimuli's parity or magnitude, depending on stimulus color. A randomly chosen positive or negative picture was presented after each stimulus, except in the performance-contingent condition, were a black screen was shown if the preceding response to the task stimulus was incorrect or too slow (> 1500 ms). In both conditions, each positive picture presentation was associated with a $ 0.1 monetary gain. The background color in the experiment was black. **B.** Group mean RTs for each contingency condition separately. Dotted lines indicate task switches and full lines indicate task repetitions. Prev con and prev incon indicate that the trial was preceded by a congruent and incongruent trial respectively. The results demonstrate how the conflict-enhanced task-switch cost, as an index of cognitive stability, is counteracted after positive affect (green) in the performance-contingent condition, and after negative affect (orange) in the non-performance-contingent condition. **C.** The bars represent the respective conflict-enhanced task-switch costs (i.e. Goschke effects) for each valence and contingency condition separately (calculated by subtracting the task-switch cost after congruent trials from the task-switch cost after incongruent trials). All error bars are ± 1 standard error of the mean (SEM).

After a short practice block of 32 trials outside the scanner, participants performed 5 experimental blocks during scanning. Each block contained 64 trials. There was a short break between blocks in which the participants could see their updated score. Each of the 32 stimulus-picture combinations (eight numbers × two task colors × picture valence) was presented ten times in a randomized order and IAPS pictures were randomly chosen from the appropriate valence group, but never reoccurred within a block. On average, participants in the performance-contingent condition would mostly end up with a slightly smaller amount than people in the non-performance-contingent condition (who always won the maximum amount: $16). However, after the experiment, participants received the same maximum amount possible, irrespective of their outcome or contingency-condition.

Behavioral data analyses

Three participants were excluded from analyses because of too few registered responses (26%, 30%, and 51% of their responses exceeded the response registration deadline). The remaining 32 participants had a mean of 3.7% (SD = 4%) of unregistered responses. There was an equal amount of men and women (eight women and eight men) assigned to each condition and age did not differ significantly (non-performance-contingent condition: mean age = 25, SD = 4%; performance-contingent condition: mean age = 27, SD = 7%), t(1,30) = 1.187, $p > .1$. Before analyses, trials following an error and the first trial of each block were removed. We carried out an ANOVA with the four within-subject factors task sequence (repetition vs. switch), current trial congruency (congruent vs. incongruent), previous trial congruency and preceding valence (positive vs. negative picture) and the between-subjects factor of contingency condition (performance-contingent vs. non-performance-contingent) on correct trial RTs and error rates.

Questionnaires

All participants completed the Behavioural Inhibition System/Behavioural Activation System (BIS/BAS) questionnaire (Carver & White, 1994) and the Positive and Negative Affect Scale (PANAS; Watson et al., 1988). These scores were used to ensure that differential effects obtained for the between-subjects factor could not be attributable to overall group differences in mood, or punishment/reward sensitivity.

fMRI data acquisition

Imaging was conducted on a GE Discovery MR750 system at 3.0 tesla using a standard head coil. We acquired functional images parallel to the AC-PC plane with a T2*-weighted single-shot gradient EPI sequence of 36 contiguous axial slices [repetition time, 2000 ms; echo time, 28 ms; flip angle, 90°; field of view, 192mm; array size, 64 × 64] with 3 mm thickness and 3 × 3mm in-plane resolution. Structural images were acquired with a T1-weighted FSPGR axial scan using a 3D inversion recovery prepared sequence, recording 120 slices of 1 mm thickness and in-plane resolution of 1 × 1 mm.

fMRI data analysis

All preprocessing steps and statistical analyses were performed using SPM8 (http://www.fil.ion.ucl.ac.uk/spm/software/spm8/). Functional data were slice-time corrected and spatially realigned to the first volume of the task. The structural image was normalized to the Montreal Neurological Institute (MNI) template brain (resampled voxel size 2 mm^3). The normalization parameters were then applied to the functional images to ensure an anatomically informed normalization. The first 5 volumes of each run in which no stimulation occurred were discarded before estimating statistical models. A 128 s temporal high-pass filter was applied to the data. Temporal autocorrelations were estimated using restricted maximum likelihood estimates of variance components with a first-order autoregressive model, and the resulting non-sphericity was used to form maximum likelihood estimates of activations. A spatial smoothing filter of 8 mm FWHM (full-width at half maximum) was applied. Event-related regressors convolved with a canonical hemodynamic response function (HRF) were created corresponding to the stimulus onsets and picture onsets of each trial defined by the same factors as the behavioural data analyses. More specifically, both picture- and stimulus-locked onset regressors were defined by the congruency of the present trial, the congruency of the previous trial, and the task sequence status (task repetition or task switch). Furthermore, the regressors of picture onsets were also defined by the picture valence of the current trial, while the regressors of stimulus onsets were defined by the picture valence of the preceding trial (because the picture of the current trial is only presented after stimulus-onset). Error trials, trials following an error, and the first trial of each run were modelled separately as nuisance variables. Single-subjects contrasts on stimulus-locked regressors were calculated to establish the hemodynamic correlates of the task-switch cost (switch > repetition) and the Goschke effect (task-switch cost following incongruent trials > task-switch cost following congruent trials). Group effects were assessed by submitting the individual contrast images to voxelwise one-sample t-tests (random-effects model). Between-group differences in the modulation of the Goschke effect by previous picture valence, as well as the effect of picture valence on picture-locked regressors were assessed by submitting the individual contrast images to voxelwise independent two-sample t-tests.

To control for false-positive rates, combined voxel activation intensity and cluster extent thresholds corrected for multiple comparisons were calculated and determined by using the 3dClustSim software package (http://afni.nimh.nih.gov/pub/dist/doc/program_help/3dClustSim.html). Specifically, the program was used to run 10,000 Monte Carlo simulations taking into account the whole-brain search volume and the estimated smoothness of each axis of the respective group SPMs to generate probability estimates of a random field of noise producing a cluster of voxels of a given extent for a set of voxels passing a specific voxelwise p value threshold, which we set at 0.005 for all analyses. Given this voxelwise threshold, the simulations determined that cluster sizes of 215 to 252 voxels, depending on the specific analysis, corresponded to a combined threshold of $p < 0.05$ (corrected).

ROI analyses

For evaluation of interaction effects, we extracted mean β estimates from empirically defined ROIs, using Marsbar software (http://marsbar.sourceforge.net/). Specifically, we extracted for each participant activation estimates from a 5 mm radius sphere centered on activation maxima in the contrast of interest and submitted the resulting values to statistical tests.

RESULTS

Behavioural data

Mean accuracy and RTs did not differ between the performance-contingent (accuracy = 89.9 %; mean RT = 834 ms) and non-performance-contingent condition (accuracy = 88.4 %; mean RT = 833 ms) and there were no differences in punishment/reward sensitivity scores (BIS/BAS) or mood scales (PANAS) between both conditions (all $t(1,30) < 1$).

As expected, there was a significant task-switch cost, in both RTs, $F(1,30) = 92.853$, $p < .001$, and error rates, $F(1,30) = 43.175$, $p < .001$, indicating higher RTs and error rates when a task alternated (870 ms, 9.8 % errors) as opposed to when the task repeated (807 ms, 5.5 %). We also observed a typical congruency effect which was expressed in higher RTs, $F(1,30) = 94.678$, $p < .001$, and higher error rates, $F(1,30) = 49.604$, $p <$

.001, for incongruent trials (882 ms, 12.6 %) as opposed to congruent trials (795 ms, 2.7 %). Additionally, we observed a main effect of previous congruency in RTs, *F*(1,30) = 10.872, *p* < .01, and a trend in error rates, *F*(1,30) = 3.824, *p* = .06: trials following an incongruent trial were slower and less accurate (847 ms, 8.3 %) than trials following a congruent trial (831 ms, 6.9 %). Furthermore, there was a significant interaction between congruency and task sequence in both RTs, *F*(1,30) = 11.378, *p* < .01, and error rates, *F*(1,30) = 23.474, *p* < .01, showing a greater congruency effect for task-switch, than task-repeat trials. As expected, a significant Goschke effect was observed in the error rates (two-way interaction between previous congruency and task sequence), *F*(1,30) = 12.361, *p* < .01, indicating a higher task switch cost following incongruent trials (6.1 %), as opposed to congruent trials (2.6 %). This effect was not observed in the RTs. However, most importantly, a four-way interaction in RTs between condition, task sequence, previous congruency, and preceding valence indicated diverging effects of the IAPS pictures on cognitive control, dependent on the contingency condition, *F*(1,30) = 10.407, *p* < .01 (Figure 1B,C). No other main effects or interactions reached significance (all *p* > .1).

In order to further investigate the four-way interaction involving the effect of IAPS picture presentation on cognitive control, we examined each contingency condition separately. In the performance-contingent condition, there was a significant three-way interaction between task sequence, previous congruency, and preceding valence, *F*(1,15) = 8.350, *p* < .05. There was a tendency for an increased task-switch cost after incongruent trials, as opposed to after congruent trials, when preceded by a negative picture (task-switch cost after incongruent trials minus the task-switch cost after congruent trials = 25 ms), *F*(1,15) = 4.271, *p* = .056, but not when preceded by a positive picture (-23 ms), *F*(1,15) = 1.637, *p* > .1. By contrast, in the non-performance-contingent condition, there was a marginally significant three-way interaction between task sequence, previous congruency, and previous valence in the opposite direction, *F*(1,15) = 3.616, *p* = .077, as the Goschke effect could be observed following positive pictures (38 ms), $F(1,15) = 5.256$, $p < .05$, but not following negative ones (-7 ms), $F(1,15) < 1$. In other words, the typical conflict modulated task-switch cost (Goschke effect) was observed following negative pictures (but not positive ones) in the performance-contingent group and following positive pictures (but not negative ones) in the non-performance-contingent group. As predicted, these results show how the affective modulation of the Goschke effect is defined by the performance-contingency of the affective pictures. Specifically, the Goschke effect, as a measure of cognitive stability (at the cost of cognitive flexibility), was counteracted after performance-contingent positive pictures, but enhanced after performance-contingent negative pictures. This is consistent with the idea that positive affect following an achieved goal signals a comfortable environment, where task focus is loosened towards a more exploratory mode (Carver, 2003; Gable & Harmon-Jones, 2011, van Steenbergen et al., 2009), while performance-contingent negative affect calls for enhanced cognitive stability (van Steenbergen et al., 2012). By contrast, non-contingent positive pictures enhanced the Goschke effect, in line with the idea that non-contingent (unexpected) positive pictures induced an approach motivation, and thus induce a narrower task focus (e.g., Gable & Harmon-Jones, 2008). Non-contingent negative pictures counteracted the Goschke effect, suggesting negative pictures triggered an avoidance state, shifting attention away from the task (e.g., Padmala et al., 2011). We next turned to the fMRI data in order to determine the neural mediators of this affective modulation of cognitive control.

fMRI data: task-switching and its modulation by previous congruency

All activations we report are whole-brain corrected at $p < .05$ (see Methods). We begin by analysing neural substrates of task-switching to provide a point of contact with the previous literature, and then move on to assess the neural correlates of the Goschke effect, that is, activations associated specifically with updating a task-set in opposition to recently activated task-set stabilization processes. As displayed in Figure 2A (and

Table 1), a random-effects analysis of the fMRI data on the task-switch cost (task-switch > task-repetition) uncovered a dorsolateral frontoparietal network, as well as the insulae, right thalamus, posterior cingulate cortex, and medial frontal cortex, consistent with typical findings from the task-switching literature (Brass & von Cramon, 2002; Braver, Reynolds, & Donaldson, 2003; Sohn, Ursu, Anderson, Stenger, & Carter, 2000).

Next, having identified the brain regions involved in task-switching *per se*, we investigated how previous trial congruency modulated task-switching activity, assessing the neural correlates of the behavioural phenomenon of enhanced switch costs following an incongruent trial (Goschke, 2000). Our results show the neural signature of the Goschke effect (switch-cost after incongruent trials > switch-cost after congruent trials) to consist of a modulation of the dorsolateral frontoparietal network and the right dorsal striatum (Figure 2B, Table 1).

This dorsolateral frontoparietal network has been widely identified as a cognitive-control (or “multiple-demand”) network that is recruited when the need for top-down control processes is high (Niendam et al., 2012; Dosenbach et al., 2006; Duncan & Owen, 2000; Macdonald, Cohen, Stenger, & Carter, 2000). Accordingly, the activations show a task-switch cost following incongruent trials, but not following congruent trials (Figure 2C). This is precisely in line with the stipulation that, following incongruent trials, extra cognitive resources are needed to deal with task-alternations due to the increased task-focus and/or enhanced task-associations after cognitive conflict, which have to be overcome in order to implement a successful switch (Braem, Verguts, Roggeman, & Notebaert, 2012; Brown, Reynolds, & Braver, 2007; Goschke, 2000; Verguts & Notebaert, 2009). However, as indicated by our behavioral results, picture valence, depending on performance-contingency, is an important modulator of the conflict-modulated switch cost, attenuating the cost following performance-contingent positive stimuli, and enhancing it following non-contingent positive stimuli. To identify the neural mediators of these modulations, we next searched for brain regions where the expression of the Goschke effect varied as a function of picture affect and performance-contingency.

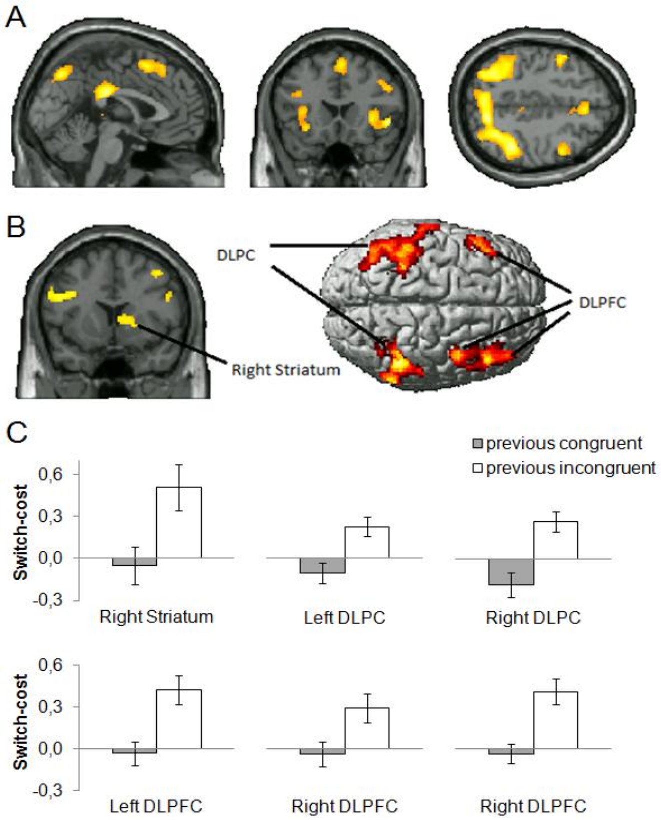


Figure 2. A. The regions identified by the stimulus-locked task-switch cost (task-switch > task-repetition) regression analysis are plotted at $p < .05$ (corrected) on sagittal (x 0), coronal (y 20), and axial (z 46) of an individual brain in MNI space. **B.** The regions identified by the stimulus-locked Goschke effect (switch cost after incongruent trials > switch cost after congruent trials) regression analysis are plotted at $p < .05$ (corrected) on coronal (y 12) and cortex surface of an individual brain in MNI space. **C.** Group mean activations for the task switch cost (switch trials - repetition trials; β estimates ± SEM) across contingency-conditions in the right dorsal striatum, left and right dorsolateral prefrontal cortex (DLPFC), and left and right dorsolateral parietal cortex (DLPC) are plotted for trials following congruent and incongruent trials, all $F(1,30) > 10.8$, $p < .005$.

fMRI data: performance-contingency and affective modulation of cognitive control

Having established our cognitive-control effect of interest, both at the behavioural and neural level, we now turn to its modulation by affect and performance-contingency. As predicted, the RT analyses demonstrated that the affective modulation of the Goschke effect was determined by the performance-contingency of the affective pictures. As shown in Figure 3A (and Table 1), a whole-brain analysis of this four-way interaction indicated the involvement of the posterior cingulate cortex (PCC), the ventromedial prefrontal cortex (vmPFC) including the pre-genual anterior cingulate, the right middle temporal gyrus (rMTG) and superior medial frontal cortex (sMFC) in this modulation.

These brain regions' activity patterns show an inverse relationship with the behavioural expression of the Goschke effect: neural task-switch costs were highest in conditions where behavioural costs were smallest in terms of RTs. Specifically, all four regions showed a significant modulation of the Goschke effect in the performance-contingent condition (all F's > 5.1, p's < .05), in that a neural signature of the Goschke effect (greater task-switch cost after incongruent trials as opposed to congruent trials) could be observed after positive pictures, which was reversed after negative pictures (Figure 3B), while reaction times showed a Goschke effect after negative pictures, but not after positive pictures (cf. Figure 1C). Both the PCC and rMTG also showed a significant modulation of the Goschke effect in the non-contingent condition, both F's > 5.2, p's < .05. In the vmPFC, this interaction reached marginal significance, $F(1,15) = 4.147$, $p = .06$, but the sMFC showed no such modulation in the non-contingent condition, $F(1,15) = 1.413$, $p > .1$.

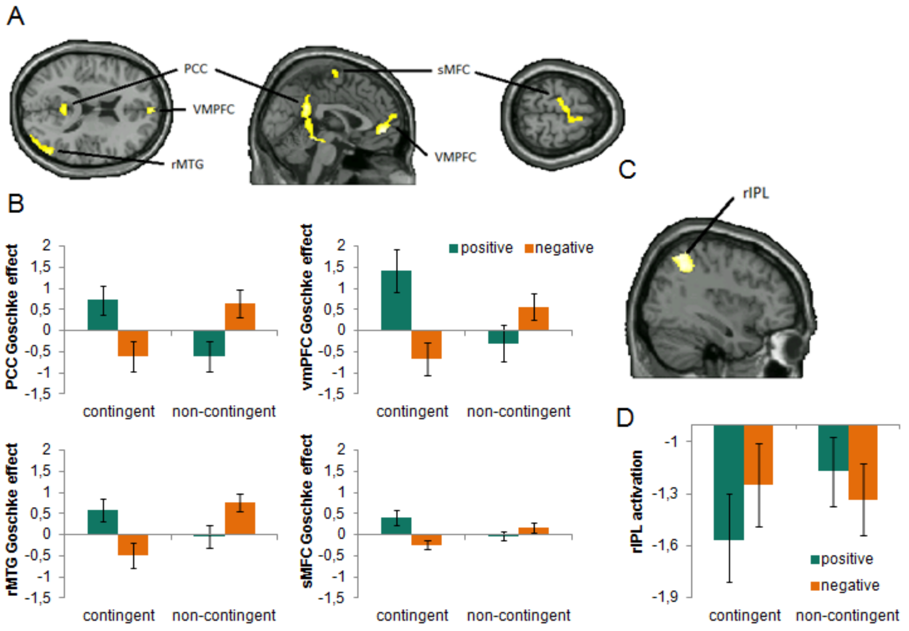
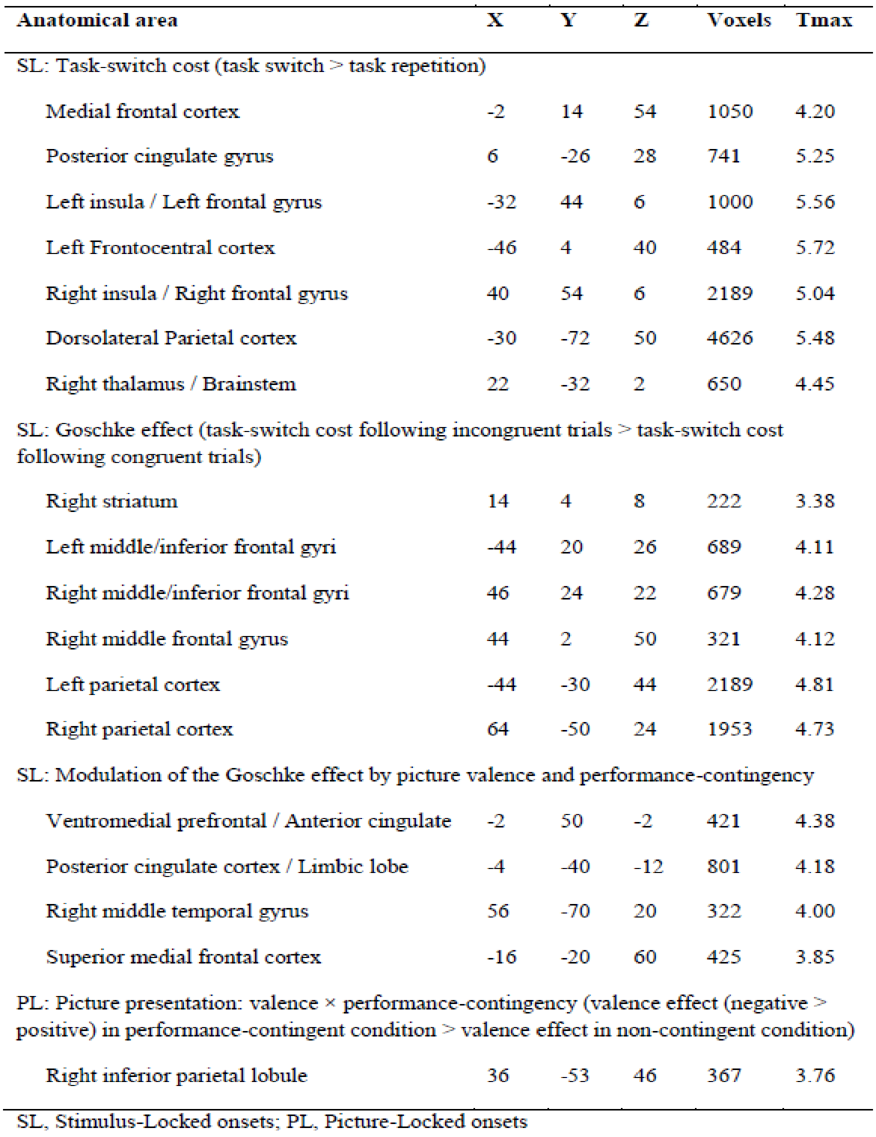


Figure 3. A. The regions identified by the modulation of the stimulus-locked Goschke effect by picture valence and contingency condition regression analysis are plotted at *p* < .05 (corrected) on axial (z 12), sagittal (x 0), and axial (z 68) of an individual brain in MNI space. **B.** Group mean activations for the Goschke effect (switch cost after incongruent trials - switch cost after congruent trials; *β* estimates ± SEM) for each contingency-conditions separately in the posterior cingulate cortex (PCC), ventromedial prefrontal cortex (VMPFC), right middle temporal gyrus (rMTG) and superior medial frontal cortex (sMFC) are plotted following positive or negative pictures, all F(1,30) > 10.4, *p* < .005. **C.** The right inferior parietal lobule (rIPL) identified by the picture valence × contingency-condition regression analysis is plotted at *p* < .05 (corrected) on sagittal (x 38) of an individual brain in MNI space. **D.** Group mean activations for each contingency-condition separately in the rIPL (*β* estimates ± SEM) are plotted for positive (pos) and negative (neg) picture presentations, *F*(1,30) = 12.3, *p* < .005.

Overall, these results suggest that heightened activity in these regions reflected the (affect- and contingency-dependent) recruitment of resources instrumental in attenuating the behavioural Goschke effect, hence enhancing flexibility. However, it could alternatively be argued that these regions simply become more active whenever control demands are relatively low, akin to areas whose activity might be released from suppression under low task demands (Gusnard, Akbudak, Shulman, & Raichle, 2001; Raichle et al., 2001). If the latter interpretation were correct, activity in these regions should be higher for any comparison between a less demanding (lower RT) with a more demanding (higher RT) condition. However, none of the regions showed a main effect of task-switch or congruency (in spite of highly significant RT effects), all *F*'s < 1.4, *p*'s > .25 (except for the sMFC, showing a marginally significant congruency effect, *F*(1,30) = 3.055, *p* = .09, with higher activations for incongruent trials). This renders an explanation in terms of a global inverse relationship with task demands implausible. Instead, our data suggest that these regions were differentially recruited to attenuate task-switch costs depending on previous congruency and the affect-induced cognitive control mode (exploration vs. exploitation). For example, positive performance-contingent affect promoted cognitive flexibility in a context dependent manner, by enhancing this network's activity on task-alternations following incongruent trials (when the enhancement of cognitive flexibility is most desirable). This is consistent with the involvement of the PCC and the vmPFC in other recent investigations of the affective modulations of cognitive control (Hart, Green, Casp, & Belger, 2010; Sakaki & Niki, 2011; Subramaniam, Kounios, Parrish, & Beeman, 2009).

Table 1. Stimulus onset locked activations revealed by the task-switch cost, the Goschke effect, and the modulation of the Goschke effect by affect and performance-contingency analyses, and picture onset locked activations revealed by picture valence × contingency condition.



Anatomical area	**X**	**Y**	**Z**	**Voxels**	**Tmax**
SL: Task-switch cost (task switch > task repetition)					
Medial frontal cortex	-2	14	54	1050	4.20
Posterior cingulate gyrus	6	-26	28	741	5.25
Left insula / Left frontal gyrus	-32	44	6	1000	5.56
Left Frontocentral cortex	-46	4	40	484	5.72
Right insula / Right frontal gyrus	40	54	6	2189	5.04
Dorsolateral Parietal cortex	-30	-72	50	4626	5.48
Right thalamus / Brainstem	22	-32	2	650	4.45
SL: Goschke effect (task-switch cost following incongruent trials > task-switch cost following congruent trials)					
Right striatum	14	4	8	222	3.38
Left middle/inferior frontal gyri	-44	20	26	689	4.11
Right middle/inferior frontal gyri	46	24	22	679	4.28
Right middle frontal gyrus	44	2	50	321	4.12
Left parietal cortex	-44	-30	44	2189	4.81
Right parietal cortex	64	-50	24	1953	4.73
SL: Modulation of the Goschke effect by picture valence and performance-contingency					
Ventromedial prefrontal / Anterior cingulate	-2	50	-2	421	4.38
Posterior cingulate cortex / Limbic lobe	-4	-40	-12	801	4.18
Right middle temporal gyrus	56	-70	20	322	4.00
Superior medial frontal cortex	-16	-20	60	425	3.85
PL: Picture presentation: valence × performance-contingency (valence effect (negative > positive) in performance-contingent condition > valence effect in non-contingent condition)					
Right inferior parietal lobule	36	-53	46	367	3.76

SL, Stimulus-Locked onsets; PL, Picture-Locked onsets

fMRI data: performance-contingency and the processing of stimulus valence

Lastly, the jittered time-interval between picture and stimulus presentation also allowed us to identify brain regions differentially activated by affect as a function of performance contingency. Consistent with our behavioural data, we hypothesized that positive affect experienced after a goal has been achieved induces an exploratory state, while non-contingent (unexpected) positive affect triggers approach behaviour towards the task, narrowing task-focus. Conversely, experiencing negative affect after a goal has been achieved calls for an enhanced task-focus, while non-contingent (unexpected) negative affect disturbs task focus. We expected that this differential modulation of attentional scope by picture valence and performance contingency would also be reflected in the brain, following picture presentation, but before actual task-performance (trial onset). The analysis investigating this (picture-locked) valence × contingency condition contrast revealed activation in the right inferior parietal lobe (rIPL, Figure 3C, Table 1). A recent literature review proposed an important role for the rIPL in flexibly reconfiguring behaviour between two different modes of attention: maintaining control on current task-goals, on the one hand, and flexibly switching to new external demands, on the other hand (Singh-Curry & Husain, 2009). This seems consistent with our behavioural data, demonstrating a differential impact of picture valence on cognitive stability/flexibility, depending on performance-contingency. Post-hoc t-tests of rIPL activity within each performance-contingency condition demonstrate how positive pictures, relative to negative pictures, significantly deactivated this region in the performance-contingent condition, $t(15) = 3.0$, $p < .01$, and, marginally significant, enhanced this region in the non-contingent condition, $t(15) = 1.9$, $p = .083$ (Figure 3D).

DISCUSSION

In this study, we set out to investigate the role of performance-contingency in defining affective modulations of cognitive control. We report four novel findings: First, in line with our predictions, we found that positive affective stimuli promoted cognitive flexibility when performance-contingent, but enhanced stability when not performance-contingent. Second, the Goschke effect, as a measure of the trade-off between cognitive stability and flexibility, was associated with activation of the striatum and a dorsolateral frontoparietal network, displaying a neural switch cost after incongruent trials, but not after congruent ones. Third, interestingly, the performance-contingency-dependent affective modulation of this effect was mediated by a different network, centered on the vmPFC/anterior cingulate and the posterior cingulate. Specifically, these regions’ activation profiles were inversely related to the behavioral expression of the Goschke effect, as modulated by performance contingency and preceding picture valence. Lastly, we documented that the rIPL might play an important role in setting up this contingency-dependent processing of affective stimuli. In the following, we discuss these findings in turn.

By explicitly manipulating performance contingency, we demonstrated how this factor determined the impact of affect on different modes of cognitive control (i.e., stability/exploitation versus flexibility/exploration). Previous studies did not manipulate, or were unclear about, the performance-contingency of affective stimuli. For example, affective stimuli were sometimes described as “reward signals” (immediately following response and accompanied by monetary gain), but were also presented following erroneous responses (van Steenbergen et al., 2009; 2012), thus rendering their interpretation ambiguous (for a discussion, see Braem et al., 2012; Dreisbach & Fischer, 2012). By systematically manipulating performance contingency in the present study, we can confirm previous conclusions that performance-relevant positive affect enhances cognitive flexibility (van Steenbergen et al., 2009; 2012). This is consistent with the hypothesis that positive stimulus presentation after an achieved goal signals that task performance is going well, and a more flexible or explorative mode of cognitive control can be permitted (Gable & Harmon-Jones, 2011). However, it has also been argued (Gable & Harmon-Jones, 2011) that this popular hypothesis of positive affect-induced cognitive flexibility (Ashby et al., 1999; Braver & Cohen, 2000; Dreisbach, 2006) is probably restricted to block-wise mood inducements (e.g., Dreisbach & Goschke, 2004) or post-goal affect (e.g., van Steenbergen et al., 2009). Our results corroborate this idea. In fact, when introducing positive pictures as performance-unrelated stimuli, these stimuli appeared to narrow rather than broaden attention. This is in line with the observation that positive pictures facilitate the detection of local (relative to global) targets (Gable & Harmon-Jones, 2008; Harmon-Jones & Gable, 2009), presumably by inducing an approach-motivated attentional state: manipulations that increase approach motivation intensity, and individual differences in approach sensitivity, have been shown to modulate this effect (Gable & Harmon-Jones, 2008). Negative affective stimuli showed the converse pattern: when task-relevant, negative stimuli signal a need for stabilizing the present task-set, directing attention towards the task (van Steenbergen et al., 2012) at the cost of cognitive flexibility. Non-contingent negative pictures, on the other hand, appear to pull attention away from the task at hand, thus broadening focus (Padmala et al., 2011).

It is important to note that this effect of performance-contingency is specific for affect-inducing stimuli, like positive and negative pictures. Other studies that used abstract colours or numbers as performance-contingent reinforcement signals (Braem et al., 2012; Stürmer, Nigbur, Schacht, & Sommer, 2011) observed an improved, rather than diminished, conflict-enhanced task-focus. This discrepancy in findings likely reflects differences in the type of post-goal stimuli used and is in line with theoretical work on the motivation of adaptive behaviour, suggesting fundamental differences in the impact of affective versus reward feedback (Berridge & Robinson, 2003; Chiew & Braver, 2011; Smith, Berridge, &

Aldridge, 2011): whereas positive pictures in the current experiment induced a post-goal positive affect, signalling a comfortable environment after successful performance (Gable & Harmon-Jones, 2011), the reward signals in the studies of Braem et al. (2012) and Stürmer et al. (2011) likely acted as mere learning signals, eliciting a more motivational component (i.e. encouraging to enhance associations after conflict).

Previous studies of affective modulations of cognitive stability mainly investigated the modulation of the congruency sequence effect (Padmala et al., 2011; van Steenbergen et al., 2009, 2012), whereas affective modulation of cognitive flexibility was investigated in task-switching studies (Dreisbach & Goschke, 2004). To test the optimal balancing between a flexible and rigid mode of cognitive control, we instead employed a single task-switching protocol where both flexibility/exploration (task-switching) and stability/exploitation (conflict control) could be investigated simultaneously. Specifically, we examined the Goschke effect (Goschke, 2000): the observation that a task-switch cost is enhanced after incongruent as opposed to congruent trials. Our fMRI data allowed us to identify the associated brain regions and uncovered enhanced task-switch costs after cognitive conflict in dorsolateral frontal and parietal cortices and right dorsal striatum. Similarly, Hyafil, Summerfield, and Koechlin (2009) observed how the dlPFC was most recruited on task-switches where both the current and preceding trial were incongruent. These activations likely represent the enhanced recruitment of a top-down cognitive-control network (Niendam et al., 2012; Dosenbach et al., 2006; Duncan & Owen, 2000; Macdonald et al., 2000) when switch processes need to be implemented in opposition to task-set reinforcement mechanisms that were activated by an incongruent stimulus encountered on the preceding trial (Botvinick et al., 2001; Verguts & Notebaert, 2009).

Adding the factors performance-contingency and picture valence, we further examined the contingency-dependent affective modulation of the Goschke effect. Interestingly, this interaction was primarily associated with activations of the PCC and vmPFC, with increased activity predictive of better performance (smaller conflict-modulated switch costs). The vmPFC and PCC are thought to be core nodes of a network that first gained popularity as the “default mode” or “resting state” network (Gusnard et al., 2001; Raichle et al., 2001) of regions commonly displaying task-negative activations (Fox et al., 2005). However, recent evidence indicates this network to be highly reactive and tuneable (Singh & Fawcett, 2008), closely tied to task control networks (Fair et al., 2008; Leech, Braga, & Sharp, 2012; Sridharan, Levitin, & Menon, 2008), and important for efficient task performance. Importantly, this network has been shown to play a critical role in facilitating cognitive control for task-switching (Hayden, Smith, & Platt, 2010) and, more generally, cognitive flexibility (Pearson, Heilbronner, Barack, Hayden, & Platt, 2011; Waltz et al., 2013), as well as the influence of positive mood thereon (Sakaki & Niki, 2011; Subramaniam et al., 2009). Lastly, the vmPFC has an important role in integrating affective and cognitive processes (Gusnard, Akbudak, Shulman, & Raichle, 2001; Vertes, 2006).

It has been suggested that goal-related positive affect fosters cognitive flexibility via dopaminergic gating signals to dorsolateral prefrontal working memory regions (Ashby et al., 1999; Braver & Cohen, 2000; Dreisbach, 2006). While we did not directly measure dopaminergic signals in the present study, we did not observe a modulation of dorsolateral prefrontal activity by affect and performance-contingency. Instead, the present data are more commensurate with an affective recruitment, conditioned on performance-relevance, of the medial vmPFC-PCC network described above (which is also subject to dopaminergic modulation, see Dang, Donde, Madison, O'Neil, & Jagust, 2012; Delaveau et al., 2010; Nagano-Saito et al., 2008; Nagano-Saito, Liu, Doyon, & Dagher, 2009). Specifically, we propose that the affective trial-to-trial modulations of cognitive control, regulating the balance between cognitive flexibility and stability in task switching, is mediated by a modulation of cingulate components of the "default mode network", where higher activation of this network is associated with enhanced cognitive flexibility (Sakaki & Niki, 2011; Subramaniam et al., 2009).

Lastly, we also investigated how picture processing itself was determined by the performance-contingency condition. This analysis uncovered the rIPL, consistent with its supposed role in regulating two different modes of attention (Singh-Curry & Husain, 2009; see also Corbetta, Patel, & Shulman, 2008): maintaining control on current task-goals on the one hand, and flexibly switching to new external demands on the other (e.g., Desmet, Fias, Hartstra, & Brass, 2011). We speculate that enhanced activity in the rIPL in the present study may have led to the further enhancement of task-relevant associations after conflict, promoting a form of cognitive stability; by contrast, this region’s deactivation would enhance cognitive flexibility, allowing a better preparation for task-switches after conflict.

In sum, our results demonstrated how performance-contingency determines the way trial-to-trial affect inducements modulate the balancing between cognitive flexibility and cognitive stability. While post-goal performance-related positive affect promoted exploration and cognitive flexibility, post-goal negative affect narrowed attention and enhanced task focus. However, non-contingent affect showed a reversed pattern. We suggest that these affective modulations of cognitive control occur via a (likely dopamine-induced) modulation of the vmPFC and PCC, "default mode network" nodes associated with cognitive flexibility. As a modulator between these different modes of attention, the rIPL might play an important role in the demonstrated differential impact of affective stimuli on cognitive stability/flexibility, depending on performance-contingency.

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CHAPTER 8
GENERAL DISCUSSION

The way we interact and navigate through our environment is characterized by the overcoming of numerous obstacles and challenges, requiring us to constantly update our choices, action tendencies, and information processing. In the lab, we investigate this by studying conflict processing: the observation that we can both monitor and learn from conflicting information as a function of efficient task performance. In the introduction of this dissertation, we described how reinforcement learning, both in its philosophy and practice, can help at further understanding the underlying mechanisms determining the way we deal with these conflicts. Over the past decades, a (still growing) offspring of reinforcement learning theories helped us exemplifying how much of our behavior can be explained by both simple and complex learning rules that strive towards maximizing reward. Motivated by this literature, we set out to examine the role of reinforcement learning in conflict processing in six empirical studies and demonstrated that (1) the way we react to conflict is subject to such learning rules (Chapter 2 and 4), (2) reinforcement signals modulate these adaptations to conflict (Chapter 3, 4, and 5), (3) the to-be-maximized reward experience can very well be part of the conflict processing itself (Chapter 6), and (4) affective states might help us in determining when to start and stop adapting to conflict, depending on how this affect is related to our performance (Chapter 7).

In this chapter, while making a short overview of our results, we will try to integrate these findings with the existing literature. To this end, we will not only recapitulate the frameworks and ideas outlined in the introduction, but also devote a special part of this discussion to incorporating both affective and reinforcement signal modulations of cognitive control. We shall also discuss some of the possible underlying neuromodulatory systems, and, finally, present some new interesting research directions, through which the role of reinforcement learning in explaining cognitive control could be further investigated.

Adaptations to conflict by Hebbian Learning

We dedicated a first part of this dissertation to investigating the underlying mechanisms of conflict adaptation. Specifically, we set out to demonstrate how adaptations to conflict can be understood by a conflict-induced Hebbian learning rule (Verguts & Notebaert, 2008; 2009). According to this model, the detection of conflict (as modeled by Botvinick et al., 2001) triggers a neuromodulatory signal throughout the brain that helps strengthening all active (task) associations. This model led us to hypothesize that, therefore, response modalities or irrelevant salient context features would be taken into account when the strengthening of associations occurs, arguing for a response- or context-specific implementation of conflict control. In line with this hypothesis, we observed in Chapter 2 how adaptations to conflict were restricted to effector (hand or feet) repetitions, versus effector alternations. Likewise, in Chapter 4, conflict adaptation was restricted to conditions where the surrounding task-irrelevant color remained the same, as opposed to color alternation conditions.

In a similar vein, Spapé and Hommel (2008) observed how the stimulus modality of an irrelevant stimulus dimension determined subsequent adaptations to conflict. Specifically, Spapé and Hommel (2008) used an auditory Stroop where the word presented on the screen indicated participant's response, while at the same time a congruent or incongruent word could be auditory presented. Notably, this auditory word presentation was brought by either a male or female voice. Their results demonstrated how adaptations to conflict only occurred when the task-irrelevant voice (male or female) repeated, versus alternated (Spapé and Hommel, 2008). The authors concluded that conflict-induced adaptations are therefore mediated by the automatic retrieval of specific episodic events (Spapé, 2009; Spapé and Hommel, 2008). This is very much in line with our results demonstrating the role of response modality (Chapter 2) and visual context (Chapter 4) in determining adaptations to conflict, but also with the more general framework of Verguts and Notebaert (2008, 2009). Other studies have further supported this idea. For example, Fischer, Plessow, Kunde, and Kiesel (2010) demonstrated how task context, rather than task load, was an important factor in predicting trial-to-trial modulations in the Simon task. Correspondingly, Hazeltine, Lightman, Schwarb, and Schumacher (2011) demonstrated how stimulus modality repetitions, but not alternations, set the stage for conflict adaptation (but see their Experiments 2 and 4). Lastly, also in the task-switching literature, Dreisbach and Wenke (2011) showed how irrelevant stimulus feature repetitions can impede task-switching performance, presumably because these features were integrated in associative learning processes after successful response executions on the previous trial.

Still, we would like to note that some studies have also observed Gratton effects across "task-sets" or stimulus modalities (Akçay & Hazeltine, 2008; Freitas, Bahar, Yang, & Banai, 2007; Hazeltine et al., 2011). Therefore, similar to our argumentation in Chapter 2, Hazeltine and colleagues (2011) argued that it is important to consider that "task-sets" can have flexible boundaries. We can predict more generalization across tasks when the tasks exhibit more overlap. However, these flexible boundaries do not only depend on such accidental task properties, but can also vary dependent on task instructions, feature saliency, and people's goals (Hazeltine et al., 2011).

Reinforcement signals modulate adaptations to conflict

Having demonstrated how adaptations to conflict can be understood by a conflict-induced strengthening of associations, we were interested in how reinforcement signals might help in bringing about this effect. In the introduction, we hypothesized that, in the spirit of reinforcement learning, the above described learning effects can be modulated by reinforcement signal processing.

In Chapter 3, we put this hypothesis to the test by presenting infrequent contingent rewards in a flanker experiment (Experiment 1), and a task-switching study (Experiment 2). Our results suggested that both the Gratton and Goschke effect were enhanced after rewarded trials, but reduced, in fact absent, after no-reward trials. This absence of a Gratton and Goschke effect was not entirely foreseen. Although the modulation of these adaptations to conflict were in the hypothesized direction, we did not predict that the sequential modulations after conflict would also be largely diminished after no-reward trials. Nonetheless, this observation is consistent with previous literature, demonstrating that reward signals often preserve otherwise observed attentional effects (e.g., Hickey, Chelazzi, & Theeuwes, 2010a; Muhle-Karbe & Krebs, 2012), while no-reward trials tend to weaken or counteract these effects[1]. Our effects are consistent with those of Stürmer, Nigbur, Schacht, and Sommer (2011), also demonstrating an enhanced Gratton effect after reward, but inconsistent with those of van Steenbergen, Band, and Hommel (2009, 2012) who showed that reward counteracts

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[1] It was exactly driven by this observation that we choose to investigate the potential rewarding nature of resolving cognitive conflict in Chapter 6. Our chapters were introduced independently in the introduction, but, in fact, our hypothesis for Chapter 6 originated from the results of Chapter 3. We hypothesized that the reward signals in Chapter 3 might have superseded motivational aspects otherwise present in tasks without an explicit reward manipulation, thereby demotivating people after no-reward trials.

conflict adaptation. Below, we will argue why we believe this might be due to the nature of the stimuli used.

In Chapter 4, we wanted to examine if our reward manipulation might also have an impact on the context-sensitivity of adaptations to conflict. Combining our preceding two hypotheses, we predicted that reward would enhance the conflict-induced strengthening of associations, and do so in a context-specific manner. Our findings confirm this hypothesis by showing how adaptations to conflict are enhanced after high reward on context repetitions, but not on context alternations. Moreover, our data shows a second pattern, in that following low reward, the Gratton effect was significant on context alternations, but not on context repetitions. Similarly, Hickey et al. (2010a) and Della Libera and Chelazzi (2009) demonstrated how low reward might act to shift attention to alternative task features, thereby strengthening associations to these, rather than target, features. However, this pattern has to be interpreted with caution. For example, in Experiment 3, the Gratton effect after low reward on context repetitions was numerically the same as on context alternations, and reached near significance. Therefore, we believe the most important message from this experiment is that reward enhances adaptations to conflict in a context-sensitive manner, but the precise conditions and mechanisms remain to be investigated.

In both Chapters 3 and 4, the magnitude of the (contextual) impact of reward on cognitive control was often predicted by the participant’s score on the BAS Reward Responsiveness subscale of the BIS/BAS personality assessment, consistent with earlier reports demonstrating a relationship between BAS subscales and the impact of reward on cognitive control or attentional selection (e.g. Hickey, Chelazzi, & Theeuwes, 2010b; Van Steenbergen, Band, & Hommel, 2009). We can see these correlations as a manipulation check reassuring us that the overall effects of the reinforcement signals were indeed reward driven, but these correlations can also be seen as support for the general idea that motivational and affective modulations of cognitive control are highly dependent on individual differences, as recently stressed by Kanske (2012).

The latter was even stronger demonstrated in Chapter 5. There, we aimed at looking into the impact of punishment signals on the Gratton effect. We assumed that, much like rewards, punishments could reinforce behavior and support the conflict-induced strengthening of associations. Although this could sound counterintuitive at first (punishments normally signal that actions should not be repeated), note that our punishment schedule (infrequently) punished erroneous, and too slow (slower than 350 milliseconds) responses only. Therefore, the punishments signaled a need for improved task performance. Although our results suggest that punishment signals reinforced adaptations after conflict, this effect was not observed for high punishment-sensitive participants. In fact, highly punishment-sensitive participants only slowed down after punishments, rather than reinforcing sequential congruency effects. Similar results were obtained in the study of Stürmer et al. (2011). Although this could indicate that all participants in the study of Stürmer and colleagues were overly sensitive to punishments, this effect may also be confounded with only punishing the slowest responses in their design. Due to autocorrelation between nearby trials, it could be more likely to observe slower reaction times after (slower) punished trials, than no-punishment trials.

Together, these three Chapters offer us interesting insights in how reinforcement signals can reinforce conflict-induced learning processes. Both infrequent rewards and punishments (when not too disruptive), irrespective of their valence, showed to uphold adaptations to conflict (Chapters 3 and 5). This is in line with the idea that arousing stimuli, notwithstanding their valence, can help at promoting the Hebbian learning processes (Verguts & Notebaert, 2008, 2009). Yet, a strict interpretation of Botvinick's model (2007) - assuming that conflict adaptation is aversiveness driven, and hence can be counteracted by reward (van Steenbergen et al., 2009) - can no longer hold, given that reward signals, assumed to induce positive feelings, did not counteract, but enhance both the Gratton and Goschke effects in our studies. In Chapter 4, our reward signals were not confounded with frequency. Note that there, we introduced both high- and low-reward signals, closely following the design of Hickey and colleagues (2010a), to test if high reward would again enhance adaptations to conflict, but now in a context-sensitive manner. Low reward trials too, modulated the Gratton effect, by enhancing it on context alternations. Therefore we believe these reinforcement signals mainly manipulated which context features would be incorporated in the conflict-induced reinforcement of associations, consistent with the overall observation of Hickey and colleagues (2010a) that low reward shifts attention towards the distractor context. Although theoretically building further on the ideas of Chapter 2 and 3, the experimental design does bear some differences with our other reinforcement signal manipulations. The low-reward signals should especially not be confused with the punishment signals used in Chapter 5. Whereas the former followed correct responses only, the latter also indicated erroneous and "too slow" responses. Moreover, the latter could be overcome, whereas the former just indicated less luck after successfully having completed a conflict trial.

The motivational significance of conflict processing

Conflict adaptation effects are a reflection of trial-to-trial conflict-induced (Hebbian) learning effects, as suggested by both their specificity to contextual features and susceptibility to learning signals. However, our next research question was to investigate what drives these learning effects in contexts without explicit rewards or punishments. We believe that the answer to this question lies in a reinterpretation of reinforcement signals, rather than trying to dismiss the applicability of reinforcement learning theories in "reinforcement-signal-free" environments. To this end - partially reciting Satterthwaithe and colleagues (2012) - we believe that being right could actually very well be its own reward. In a similar vein, Aarts, De Houwer, and Pourtois (2012) demonstrated how correct responses are more positively evaluated than errors. Therefore, Chapter 6 was set up to test the hypothesis that resolving cognitive conflict can be perceived as more positive, or rewarding, countering its negative evaluation before response execution (Dreisbach & Fischer, 2012; Fritz & Dreisbach, in press).

In line with this prediction, we demonstrated that, while observing incongruent trials (relative to congruent trials) can be perceived as negative (our Experiment 1, replicating Dreisbach & Fischer, 2012; Fritz & Dreisbach, in press), responding to these trials was experienced as positive (our Experiments 2 and 4). Furthermore, in testing if this was specific to overcoming conflicting information for efficient task performance, we tested if also overcoming a similarity judgment would be followed by a more positive emotion. The latter, according to our Experiment 3, was not the case. In fact, if anything, the affective priming paradigm suggested more negative feelings after dissimilar (difficult), than similar (easy) trials. This could indicate that our effect in Experiments 2 and 4 is specific to overcoming conflict. However, we believe this interpretation should be treated with caution, for a number of reasons. First, we only tested one other paradigm manipulating task difficulty. It could be that the non-existence of our effect could be due to the less motivating aspect of this task, rather than the unique motivating aspect of conflict tasks. Second, Satterthwaithe and colleauges (2012), who did not use a conflict task but an n-back task where participants need to indicate if a figure is identical to the n-th preceding trial (varying n as a measure of difficulty), did find enhanced ventral striatum activation (usually associated with feelings of reward), after correct as opposed to incorrect trials; an effect that grew as a function of task difficulty. Third, the RVPM model of Silvetti and colleagues (2011) predict this effect only on the basis of outcome expectancies and, hence, does not differentiate between different sorts of task difficulty. Still, Experiment 3 does come to suggest that task difficulty alone, might not be sufficient for expecting enhanced positive feelings after successful task performance.

Performance relatedness of affect determines affective modulations of conflict control

In our last empirical chapter, Chapter 7, we studied if adaptations to conflict, understood as a manifestation of conflict-induced cognitive stability, would be modulated by affect, and if so, which role performance contingency would play therein. We demonstrated how the Goschke effect was promoted following performance-contingent negative pictures, and non-contingent positive pictures, but counteracted after performance-contingent positive pictures and non-contingent negative pictures. These results are consistent with the idea that only following contingent positive pictures, a feeling of post-goal affect signals that a more exploratory mode can be permitted, thereby counteracting the Goschke effect (Carver, 2003; Gable & Harmon-Jones, 2011, van Steenbergen et al., 2009), while after contingent negative pictures, a higher need for task focus is being called for, resulting in an enhanced conflict-induced strengthening of associations (van Steenbergen et al., 2012). Following non-contingent pictures, this observation was reversed, consistent with the idea that non-contingent negative pictures might distract attention away from the task (see also Padmala, Bauer, & Pessoa, 2011). Padmala and colleagues even observed counteracted conflict adaptations and overall slower response times after non-contingent negative pictures, but note that their picture set included more salient negative pictures (such as mutilated corpses) than ours, which were presented immediately after the response and half a second before next stimulus presentation. In contrast, non-contingent positive pictures can induce an approach motivation, moving attention towards the task and its ongoing strengthening of associations (Gable & Harmon-Jones, 2008; Harmon-Jones & Gable, 2009).

Most importantly, these results come to stress the importance of taking into account performance contingency when investigating inter-trial effects of affective stimuli. This clearly demonstrates that, for example, arousal alone, irrespective of its task relevance, cannot be the sole contributor to modulations of conflict-induced strengthening of associations (Verguts & Notebaert, 2009). Secondly, our results suggest that the observations that positive affect counteracts (van Steenbergen et al., 2009), while negative affect enhances adaptations to conflict (van Steenbergen et al., 2012), only holds for affect inducements introduced as relevant for task performance. However, these results stand in sharp contrast with our findings from Chapter 3, suggesting seemingly diverging effects for reward signals and performance-contingent positive affect inducements.

In these next paragraphs, we would like to explore the different frameworks that could either integrate or disambiguate our findings, but also demonstrate how Chapter 7, although convincingly stressing the importance of performance contingency in affect modulations, only offers a first step towards exploring the exact mechanisms responsible for affective modulations of cognitive control. In our introduction, we already suggested some potential underlying factors that might lie at the root of our differential results between Chapter 7 and Chapters 3, 4, and 5. However, in what follows we would like to tentatively extend this discussion to other factors that could have played an important role in creating these different effects of affective and motivational variables on adaptations to conflict.

ON THE THIN LINE BETWEEN REWARD AND AFFECT: REWARD AS A DIMENSION

In our introduction, but also in the preceding part of this discussion, we often kept reinforcement signals and affect as separate entities. We explicitly distinguished the beneficial effects of reinforcement signals on adaptations to conflict (Chapters 3 to 5), from the effects of affect on cognitive stability and flexibility (Chapter 7; Dreisbach & Goschke, 2004). This dissociation has had its benefits in that it assures the best link to previous literature and studies, and it has been argued and demonstrated that both might have different, sometimes opposing, effects on cognitive control and attention (Berridge & Robinson, 2003; Chiew & Braver, 2012). Indeed, our results corroborate this idea, by demonstrating how performance-contingent reward signals enhanced the Goschke effect (Chapter 3), while performance-contingent positive affect counteracted the Goschke effect (Chapter 7).

But are those two all that different? And if so, where do they diverge? There is often a thin line between studies that investigate the one or the other, making it sometimes hard to distinguish the effects of reward from positive affect (Aarts et al., 2012; van Steenbergen et al., 2009, 2012). Therefore, we cannot pretend that reward and positive affect are entirely independent constructs. For example, we took the observation of facilitated responses to positive affective words as possible evidence for the rewarding aspect of overcoming cognitive conflict (Chapter 6), clearly assuming that positive affect is an inherent part of the reward experience. This is referred to as the hedonic aspect of reward (Berridge & Robinson, 2003) and is even more apparent when emotional symbols are used to signal reward. Although most studies use monetary gains denoted by (relatively) abstract symbols (our Chapters 3 and 4, Krebs, Boehler, & Woldorff, 2010; Hickey et al., 2010a, 2010b; Lu et al., 2013; Padmala & Pessoa, 2011; Savine & Braver, 2010; Stürmer, Nigbur, Schacht, & Sommer, 2011), some have used smiley faces or affective pictures to indicate the monetary gain (our Chapter 7; van Steenbergen, Band, & Hommel, 2009; 2012).

In that respect, the main difference between Chapters 3 and 4 on the one hand, and Chapter 7, on the other, lies in the different type of reward[2] signal used (for an overview on different kind of emotional stimuli, see Okon-Singer, Lichtenstein-Vidne, & Cohen, in press). Specifically, when salient enough, the effect of the hedonic aspect of reward might override the motivational part of reward (a dissociation following the theoretical work of Berridge & Robinson, 2003; Smith, Berridge, & Aldridge, 2011), thereby signaling a comfortable environment after successful performance (Carver, 2003; Gable & Harmon-Jones, 2011), allowing for a more exploratory mode. In contrast, the reward signals used in Chapter 3 and 4 or the studies of Stürmer et al. (2011) likely acted as mere learning signals, mainly eliciting a motivational component (i.e. encouraging to enhance associations after conflict). The latter might entail a higher motivational saliency, as suggested by Gable and Harmon-Jones (2011), therefore bringing about a form of pre-goal affect (the overall goal, getting the best score, has yet to be achieved).

Consider the following analogy: Imagine you are playing pinball at the arcade. The main goal is to keep the steel ball away from the drain by using two hand-controlled "flippers" to gather as many points as possible.

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[2] Feeding into this difficult dissociation is the divergent use of the term reward. Note that Merriam-Webster's dictionary defines reward both as "something that is given in return for good or evil done or received or that is offered or given for some service or attainment" and "a stimulus administered to an organism following a correct or desired response that increases the probability of occurrence of the response". This first definition is the definition we have been using throughout this dissertation, only describing the intended manipulation of the experimental design, but not its effect. The second definition, derived from early learning psychology, already implicates the anticipated effect that it will reinforce the behavior it follows.

As you will see your score raising, you can experience those as reward signals narrowing your focus and helping you to concentrate on the game. However, secondary objectives and bonus missions can maximize your score even faster. Achieving those bonus missions or breaking a record, often indicated by a victory song or flickering lights, will get you even more excited, up to the point this might bring you in a positive mood which will broaden your focus, and increase distractibility. Similarly, our reward signals in Chapters 3 and 4 helped us focusing at the task, while the more salient reward signals in Chapter 7 (affective pictures) induced a positive mood and exploratory focus, counteracting task focus, but facilitating task switching.

This dissociation does not necessarily have to constitute a dichotomy in reward signal type. Rather, it could also represent both ends of a continuum, where the more salient or affective a reward signal becomes, the more it will bring the subject into a positive (long- or short-term) mood, setting the stage for an exploratory mode of cognitive control. When, on the contrary, the reinforcement signals are more basic, merely providing somebody with informatory feedback, this person will try to integrate this feedback by reinforcing (ongoing) task association updating processes. Optimally, this hypothesis could be tested in a paradigm where the saliency or magnitude of affective stimuli is parametrically manipulated, best taking into account individual differences in responsiveness to these stimuli. Such a design could potentially demonstrate how reward signals are most efficient, when not too salient (for a similar reasoning on punishment signals, see Chapter 5).

Interestingly, in a recent review, Bijleveld, Custers and Aarts (2012) suggested that rewards can be processed on different levels. When rewards are presented only briefly, or time does not permit a full processing of the reward signal, rewards are only processed in a rudimentary form, quickly updating task associations and facilitating task performance. However, when rewards can be processed more fully, more strategic decisions can be made and the effect on performance can then diverge from those of initial reward processing. We believe this framework can also apply to the above-described dissociation between our Chapters 3 and 4, and Chapter 7: When time is short and reward signals are basic, rewards result in a quick reinforcement of the ongoing learning processes. However, when the inter-trial interval was prolonged, and rewards were more salient, the rewards signals promoted an exploratory mode, helping at counteracting the conflict-induced strengthening of associations that are disadvantageous for task-switching.

LOOKING AT THE NEGATIVE SIDE OF THINGS

Besides the reinforcing aspects of reward and the broadening of attention after positive affect, we also looked into punishment signals and negative affect. Similar to the debate on positive affect and reward (Chiew & Braver, 2011), models of cognitive and affective control often treat the effects of punishment and negative affect interchangeably (e.g., Botvinick, 2007; Shackman et al., 2011). These models are aimed at unifying and integrating, rather than specifying, the potential effects of punishment, affect and cognitive conflict. However, we argue that a dissociation addressing the performance-contingency of negative affect is of prime importance for modeling its resulting effects on cognitive control. We demonstrated how negative affect, when performance-contingent, can promote conflict-induced cognitive stability. However, when non-contingent, negative affect will most likely distract attention away from the task, disrupting the ongoing enhancement of associations after conflict (Chapter 7). In our punishment study, Chapter 5, we demonstrated how punishment signals also promoted the Gratton effect, as far as people were not too sensitive to punishment. Similar to unexpected non-contingent negative affect (Chapter 7), subjects' attention was distracted away from the task, when punishment signals were perceived as too salient (Chapter 5). Attentive readers may wonder why attention was not captured away from the task (impeding rather than promoting cognitive stability) in the performance-contingent condition of Chapter 7 as well, given that the negative pictures could easily be considered more arousing than the depictions of "-1" in the punishment task (Chapter 5). However, we believe that at least three factors may have dampened the arousing aspect of the pictures used in Chapter 7, relative to the punishment signals in Chapter 5. First, both the time intervals between response and feedback signals and feedback signals and the next trial were more than three seconds longer (per interval) in Chapter 7, than Chapter 5. Second, the punishment signals in Chapter 5 were infrequently presented relative to no-punishment trials, while the performance-contingent negative pictures Chapter 7 were equally often presented as their positive counterparts. Third, the negative pictures in Chapter 7 did not influence monetary status, meaning bad luck after correct responses, while the punishment signals in Chapter 5 did affect the score and could be avoided by responding (very) fast.

AROUSAL AFTER ALL?

As introduced above, Verguts and Notebaert (2009) suggested that the arousing value of stimuli, irrespective of their valence or task relatedness, can help at reinforcing ongoing Hebbian learning processes that underlie the adaptations to conflict. We already refuted this hypothesis by demonstrating how task relatedness or performance contingency can, in fact, play a major role in the affective modulations of cognitive control (being the take-home message of Chapter 7). This suggests that the way we deal and interact with affectively salient stimuli largely depends on what they tell us about our performance. However, although we drew conclusions about the valence dimension of our affective stimuli, the arousal dimension was insufficiently controlled for. We did not measure skin conductance responses, alpha power, or pupil dilations (although we are currently analyzing data looking into pupil dilation measures), generally recognized as physiological measures of arousal. Both our reward (Chapter 3) and punishment (Chapter 5) data could be considered as a demonstration of enhanced conflict adaptation as a result of arousal-inducing signals, albeit only when task-relevant (see control experiments Chapter 3). Similarly, in Chapter 7, the negative pictures can also be considered more arousing than the positive pictures. We did not measure arousal responses in those stimuli, nor did we assess arousal ratings by the participants themselves. However, according to the IAPS database, the negative pictures we selected were scored slightly, but reliably, more arousing than the positive pictures. By nature, negative information is more arousing than positive information (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Rozin & Royzman, 2001), and this was also reflected in the IAPS database. We deliberately chose to match the negative and positive pictures on their semantic content (e.g., smiling vs. crying child, for a similar reasoning see Taylor, Phan, Decker, & Liberzon, 2003; Waszak & Pholulamdeth, 2009), rather than to match arousal levels as this would yield an artificial selection of high arousing positive pictures (often erotic) or an artificial selection of low arousing negative pictures (often non-living things). Therefore, the negative pictures we selected did not only differ in valence, but also in arousal. This could mean that the Goschke effect promoted by performance-contingent negative pictures is driven by its arousing value, rather than the valence of these pictures.

Consistently, some studies investigating the effects of task-relevant emotional stimuli, have demonstrated how emotional saliency, irrespective of the valence, can facilitate task performance. For example, while Verbruggen & De Houwer (2007) observed how task-irrelevant emotional stimuli impeded response inhibition (see also Blair et al., 2007), Pessoa, Padmala, Kenzer, and Bauer (2011) demonstrated how emotion can also improve response inhibition, when using these emotional stimuli as stop-signals (i.e., making them task-relevant). Similarly, while task-irrelevant emotion has been shown to interfere with cognitive conflict processing (Hart, Green, Casp, & Belger, 2010; Padmala, Bauer, & Pessoa, 2011), task-relevant emotional stimuli (making the emotional stimuli the target), did seem to speed up conflict resolution (Kanske & Kotz, 2010; 2011a; 2011b). Taken together, these studies demonstrate how emotional arousal, irrespective of valence, can help at a faster processing of the target, hence facilitating conflict processing.

However, to the best of our knowledge, no study has ever investigated the effect of emotional arousal in performance-contingent feedback trials (for example by comparing to neutral pictures) on conflict adaptation processes. Studies that did control for arousal, investigating the influence of picture presentation (van Steenbergen, Band, & Hommel, 2011), or mood inducements (Larson, Gray, Clayson, Jones, & Kirwan, in press; van Steenbergen, Band, & Hommel, 2010), on conflict control did not notice an effect of arousal over valence (but see Demanet, Liefooghe, & Verbrugge, 2011, showing an effect of arousal, rather than valence, in voluntary task-switching). To better dissociate the affective from arousing effects of feedback stimuli on adaptations to conflict dependent on performance contingency, simultaneous assessment of physiological arousal measures would be required.

SKINNER UNDER THE SKIN:
BRAIN REGIONS AND NEUROTRANSMITTER FUNCTIONS

In his review on fifty years of Behaviorism, Skinner consistently talked about processes "under the skin" (Skinner, 1963), and refused to describe these processes as long as they are not observable. Fifty years later, scientific progress has much progressed and now allows us to simultaneously measure brain activity while performing experimental paradigms, exponentially increasing insights into how neurophysiological variables can help explaining our everyday behavior.

Most models of conflict adaptation (Botvinick, 2001; Verguts & Notebaert, 2009) assume that conflict is being monitored by the ACC, while the updating of task sets following conflict occurs in the dorso-lateral prefrontal-cortex (DLPFC). Consistently, studies that examined the Gratton effect inside the scanner, demonstrated how the DLPFC is differentially recruited following incongruent trials (e.g., Egner & Hirsch, 2005a, 2005b; Kerns, 2006; Kerns et al., 2004; van Veen & Carter, 2006), guaranteeing more efficient conflict processing. In our study, we chose to investigate an alternative indexation of adaptations to conflict: the Goschke effect, or the observation of an enhanced task-switch cost following incongruent trials. By pairing a task-switching experiment with functional magnetic resonance imaging (fMRI) in Chapter 7, we examined if the enhanced task-switch cost following incongruent trials would reflect a similar neural signature as the well-studied Gratton effect. Indeed, our Goschke effect was similarly reflected in enhanced DLPFC, but also striatum, activation on task alternations relative to task repetitions, following incongruent trials only. We believe this reflects an enhanced recruitment of these task-set reconfiguration networks to adapt to the less-prepared-for task alternations after the strengthened task associations following conflict. Similarly, Hyafil, Summerfield, and Koechlin (2009) demonstrated more DLPFC activation on task alternations, where both the previous and current trial were incongruent. Hyafil and colleagues (2009) further argued and demonstrated that only the DLPFC, but not the ACC, played a role in dealing with the interfering enhanced task-focus after cognitive conflict (Botvinick et al., 2001, Verguts & Notebaert, 2009). The ACC, modulated by the overall switch cost, only configures the priorities associated with the new task (Hyafil et al., 2009). We did not observe the ACC in our task-switch contrast, but a ROI analysis on the medial frontal cortex (just dorsal to the ACC) identified in our above discussed task-switch contrast showed no modulation of the switch cost by previous congruency ($p > .1$), similar to Hyafil et al. (2009).

Although not discussed in Chapter 7, we also looked at the conflict contrast, responsible for triggering the conflict-enhanced task-switch cost (the Goschke effect). This congruency effect (incongruent > congruent trials) was associated with motor cortex and striatum, but no ACC, activation. The striatum activation could reflect increased intrinsic motivation after successful response execution (Lutz, Pedroni, Nadig, Luechinger, & Jäncke, 2012), which has been found to increase with task-difficulty (Satterthwaite et al., 2012). One step further, our data could even suggest that the striatum (Humphries & Prescott, 2010), rather than, or next to, the ACC, might have played an important role in signaling for subsequent adaptations (the striatum has been suggested to play an important role in adaptive behavior following conflict, Silvetti et al., 2011). Consistently, a recent review on the ACC (Mansouri, Tanaka, & Buckley, 2009) concluded that, despite its active role as monitor, its importance in regulating subsequent behavior and signaling for adaptations to other brain regions is still uncertain. Still, the ACC has been observed in many other conflict tasks (Botvinick et al., 2001; Carter & van Veen, 2007), and was recently shown to be crucial for bringing about the Gratton effect, as evidenced after a surgically targeted ablation of the ACC (Sheth et al., 2012). Interestingly, the ACC entertains connections to noradrenergic and dopaminergic neurotransmitter systems, both having been modeled as crucial learning signals in reinforcement learning processes, such as Hebbian learning (e.g., Montague, Dayan, & Sejnowski, 1996; Verguts & Notebaert, 2009), the exploitation/exploration balance (e.g., Aston-Jones & Cohen, 2005; Cools & D'Esposito, 2011; Frank, Doll, Oas-Terpstra, & Moreno, 2009), and reward learning (e.g., Holroyd & Coles, 2002; Sara, 2009).

Although there have been first studies looking into the role of such regions home to dopaminergic (Boehler et al., 2011a; 2011b; Satterthwaite et al., 2012) or noradrenergic (Krebs, Fias, Achten, & Boehler, in press) neuron populations in cognitive control performance, no study, to our knowledge, has demonstrated a functional role of these regions in conflict adaptation. However, van Bochove, Van der Haegen, Notebaert, and Verguts (in press) demonstrated how adaptations to conflict varied as a function of eye-blink behavior, as a measure of dopaminergic activity, but not pupil dilation, as a measure of noradrenergic activity. Moreover, in line with this idea, Duthoo and colleagues (submitted) demonstrated how dopaminergic medication determined if Parkinson disease patients adapted to conflict or not. By contrasting Stroop task behavior once on medication, once following overnight withdrawal, Duthoo and colleagues demonstrated how the Gratton effect persisted following overnight withdrawal, but was absent on dopaminergic medication. These results were interpreted in terms of a dopamine overdose hypothesis (Cools & D'Esposito, 2011) stating that the medication may have overdosed relatively preserved brain regions in Parkinson disease patients, such as the ventral striatum and prefrontal cortex, thereby impeding adaptations to conflict. While this study offers some first interesting insights in the possible primary neurotransmitters responsible for conflict control, more studies are needed to unfold the precise functions essential for adaptations to conflict. In that respect, a more systematic investigation of these neurotransmitters and associated brain regions (and their relation to the common ACC-DLPFC loop) would be desirable, and might benefit from the already developed models on noradrenaline and dopamine learning (e.g. Montague, Hyman, & Cohen, 2004), reminiscent from reinforcement learning principles.

Another avenue to approach this research question of how reinforcement learning can help at uncovering the brain regions important for conflict adaptation would be by investigating the impact of reinforcement learning signals inside the scanner. Therefore, in Chapter 7, we also investigated the impact of affective pictures on the Goschke effect. Moreover, we were interested in how these affective variables could impact adaptations to conflict differently, depending on the performance contingency of these pictures. Yet, because neuroscience models of affective modulation of cognitive control (Ashby, Isen, & Turken, 1999; Gray, 2001; Pessoa, 2008, 2009; Shackman et al. 2011) are unclear about the exact role of performance-contingency (Chiew & Braver, 2011), the neural signature of these type of trial-to-trial interactions between emotion and cognition is still unidentified. For example, in their adaptive control hypothesis, Shackman and colleagues (2011) demonstrate how the ACC makes a similar functional contribution to negative affect, punishment, and cognitive control, but make no dissociation between the potentially diverging effects of task-irrelevant negative affect or tasks-relevant negative affect and punishment.

Interestingly, although our overall Goschke effect was reflected in the differential recruitment of striatal and dorsolateral frontopariatal regions, its interaction with affective picture presentation, dependent on performance contingency, was mainly reflected in a network surrounding activations of the posterior cingulate cortex (PCC) and ventromedial prefrontal cortex (vmPFC). Specifically, activity in those regions was increased when performance was fastest, following an inverse function of the respective Goschke effects. This is consistent with the involvement of this network in facilitating cognitive control for task-switching (Hayden, Smith, & Platt, 2010) and, more generally, cognitive flexibility (Pearson, Heilbronner, Barack, Hayden, & Platt, 2011; Waltz et al., 2013), as well as the influence of positive mood thereon (Sakaki & Niki, 2011; Subramaniam et al., 2009). Note that contrary to the theories suggesting that positive affect might promote cognitive flexibility via dopaminergic gating signals to the DLPFC (Ashby et al., 1999; Braver & Cohen, 2000; Dreisbach, 2006), our data shows a modulation of this PCC-vmPFC network. However, the modulation of these regions could still be driven by dopaminergic modulations (Dang, Donde, Madison, O'Neil, & Jagust, 2012; Delaveau et al., 2010; Nagano-Saito et al., 2008; Nagano-Saito, Liu, Doyon, & Dagher, 2009). Further studies, where both the effects of affective modulations and dopaminergic medication are investigated in the scanner could offer new perspectives on this topic.

CONFLICT MONITORING AND REINFORCEMENT LEARNING: AN OVERARCHING FRAMEWORK?

When introducing this dissertation, we stressed how the rich history of reinforcement learning theory can contribute to a better understanding of complex cognitive control behavior. Inspired by the accumulating models, theories, and data on this topic, we will now outline a framework in which, we believe, adaptations to conflict can be best understood. We hypothesized and demonstrated how one of the hallmark effects of cognitive control, the Gratton effect, could be reinterpreted in terms of conflict-induced Hebbian learning (Verguts & Notebaert, 2008, 2009). This model of Verguts and Notebaert (2008, 2009) offers a highly parsimonious approach to unraveling the underlying mechanisms of conflict-induced "cognitive control". However, we also believe it falls short on some issues.

Most importantly, as a learning signal for initiating or modulating this Hebbian learning process, the model defines the reinforcement factor δ as conflict-likelihood, associated with an increased arousal response helping to strengthen associations throughout the brain. The only way the model allows for reinforcement signals or other variables to influence this monitoring process is by adding more arousal to this conflict-induced Hebbian learning process (Verguts & Notebaert, 2009). However, we demonstrated how the evaluation of a response outcome can significantly impact the conflict-induced Hebbian learning process and this impact goes well beyond the mere effect of arousal alone. Therefore, we believe a computation of conflict that includes task performance and outcome expectancies would be more desirable.

Another approach could be to follow the suggestion of Botvinick (2007) and argue that adaptations to conflict are motivated by their aversive nature, inducing an avoidance response away from mental effort. Although Botvinick's suggestion probably applies well to voluntary choice and decision making paradigms (Kool, McGuire, Rosen, & Botvinick, 2010; but see Orr, Carp, & Weissman, 2012), a constant focus on the aversive nature of mental effort in forced-choice paradigms might soon be counterproductive. Again, also Botvinick's suggestion only describes the influence of conflict and the therewith associated affect, but not the subsequent performance that follows it, whereas we believe that the response following conflict is actually an important aspect of the conflict experience that could even alter its affective value.

In fact, when people cannot avoid an obstacle, they might actually find pleasure in successfully overcoming it, effectively turning a negative event into a positive one. We introduced and tested this prediction by demonstrating how correct responses to incongruent trials, relative to congruent trials, resulted in a more positive state. A model successfully capturing this idea is the reward value and prediction model (RVPM) of Silvetti and colleagues (2011). Following the principles of reward maximization reminiscent to reinforcement learning theories, the RVPM explicitly models how cognitive conflict can initially be perceived as negative (due to its low outcome expectancy), but, upon resolution, rapidly changes into a positive evaluation. Furthermore, it incorporates not only both conflict experience and conflict resolution, but also applies to reinforcement signal or error processing. For these reasons, this monitoring function could serve well to signal adaptations to conflict and the influence of reinforcement signals thereon.

However, the next question that poses itself is what component of the RVPM would signal this need for subsequent adjustments: (1) the negative prediction error during conflict processing, or (2) positive prediction error during conflict resolution, or, if there are any, (3) the reinforcement signals? Earlier, we tentatively suggested that the potential rewarding aspect of conflict resolution could be what motivates adaptations to conflict. However, a conclusion that only correct responses on incongruent trials signal conflict adaptation would be too preliminary, but also unlikely. Even our own data suggests that the potential rewarding feeling after correctly responding to an incongruent trial does not exclusively promote adaptations to conflict: Subsequent reinforcement signals or affective variables can play an important role, too.

Therefore, we would like to stress that the motivational significance of cognitive conflict is a product of the aversive nature of cognitive conflict, as well as the rewarding impact of successfully overcoming it, and, potentially, the reinforcement signals. We propose that all processing stages can contribute to the potential signaling for Hebbian learning. Specifically, we believe that conflict monitoring processes already start at the initial (aversive) experience of conflict processing itself. This idea is commensurate with the observation that within-trial conflict processes already feed into (or constitute) the adaption processes that influence the subsequent trial (Scherbaum, Fischer, Dshemuchadse, & Goschke, 2011). Still, although adaptation processes could be initiated early in time, they are constantly subject to modulation by, for example, the conflict resolution experience, as well as potential reinforcement signals that follow this. Therefore, the RVPM, which constantly updates reward value predictions, should be able to incorporate the impact of both conflict detection, and resolution, and reinforcement signal parameters on subsequent performance.

Following the RVPM, a higher reward prediction error could signal the higher need for cognitive control. However, to approximate the behaviorally observed influence of affective and motivational variables on cognitive control, an inverted U-shape, rather than a strictly linear, function between the absolute value of the reward prediction error signal and the strengthening of associations might even be more appropriate (e.g., Grant & Schwartz, 2011; Hills & Hertwig, 2011). This way, we could model how increased saliency of (or sensitivity to) punishment signals would be associated with more efficient (re)focusing on task performance up to an optimal point, after which even higher levels of saliency might only act to distract attention away from the task at hand. Similarly, the functionality of reward signals in strengthening associations for ongoing behavior can raise as a function of reward salience (or reward sensitivity), where after even more salient or affective reward signals will signal a positive mood and induce a more exploratory mode enhancing task flexibility, but impeding task focus. Error monitoring too, might signal the need for strengthening associations as a function of an inverted U-shape. We briefly touched upon this idea in Chapter 5, stating that (infrequent) errors, in contrast to incongruent trials, send higher reward prediction errors, causing people to slow down at first (Notebaert et al., 2009), before adapting task performance.

A last topic that we did not address in the empirical studies of our dissertation, but that also calls for our attention in modeling conflict control behavior, is the idea that context, rather than conflict, might drive adaptations to conflict (Schlaghecken & Martini, 2012). This idea was recently supported by two studies (Compton, Huber, Levinson, & Zheutlin, 2012; Lamers & Roelofs, 2011) that both suggest that congruent, rather than incongruent trials, might be driving the Gratton effect (but see Desender, Van Lierde, & Van Den Bussche, 2013). Note that none of our studies implemented neutral trials, hence the impact of incongruent trials was always computed relative to congruent trials. The original conflict monitoring system as implemented in the models of Botvinick and colleagues (2001) and Verguts and Notebaert (2008; 2009) calculates a form of conflict likelihood and thus predominantly focuses on detecting and resolving conflict. Although those models can also explain the effects of congruent trials (or the absence of conflict) by a loosening of task parameters after congruent trials, the main message of Schlaghecken and Martini (2012), we believe, is a re-emphasis on how cognitive control is not driven by a relative measure of conflict alone. By implementing a monitor as described by Silvetti and colleagues (2011), conflict itself loses its special value, because the outcome expectancies and performance statistics, rather than the conflict itself, would be what determines the need for adaptation. Therefore, inherent to its architecture, the RVPM itself models context, rather than conflict.

Note that these above-mentioned postulations represent guidelines, rather than axioms, which we believe, based on our empirical data and reviewed literature, might help in contributing to a broader perspective on conflict monitoring and the influence of reinforcement learning (signals) thereon. At the very least, we think these suggestions (which are obviously not exclusively ours) can help spark up the ongoing debate on the roles of reinforcement learning and reinforcement signals in conflict monitoring and cognitive control. Below, we will outline some future directions, suggesting how some of the here presented ideas can be examined.

FUTURE DIRECTIONS

The purpose of this dissertation was to examine the interactions between conflict monitoring and reinforcement learning, which soon led us to reinterpret the conflict adaptation effect as a reinforcement learning process itself. We hope our work will help towards a deeper understanding of how we adapt to our everyday ever-changing environments, motivating others to either confirm, specify, or falsify, the findings and ideas presented in this thesis. Therefore, we will end this dissertation by presenting some possible ways as to how the role of reinforcement learning in explaining conflict monitoring (and beyond) could be further examined.

In this work, we fostered the idea that adaptations to conflict, as a well-studied manifestation of cognitive control, would be subject to a conflict-induced Hebbian learning rule. By using this framework, we could exemplify how associative learning processes can underlie flexible trial-to-trial behavioral adaptations. The adaptation-by-binding model naturally extends its predictions to all conflict-induced forms of learning. For example, we demonstrated how also the Goschke effect (Goschke, 2000) could be seen as a very similar indexation of conflict-induced Hebbian learning. Another prime example of this mechanism could be seen in the asymmetrical task-switch cost (Allport, Styles, & Hsieh, 1994). The asymmetric task-switch cost is the finding that in task switch studies with two tasks of differing task difficulty, task-switch costs are larger for the easier task, than for the more difficult task. That is, people experience more difficulty when switching to the easier task, than switching to the more difficult task. This is typically studied within a vocal Stroop task with incongruent stimuli only, where participants have to switch between word-naming (easier) and color-naming (more difficult task). Again, the model of Verguts & Notebaert (2009) could explain this by strengthening task-relevant connections after conflict. After performing the color-naming task (more conflict), subjects strengthen their task-relevant connections. This makes it more difficult to switch to the easier task, thereby increasing the task-switch cost. By examining the (motivational, context-specific, etc.) modulations of such effects, next to the popular Gratton effect, we can expand our knowledge on trial-to-trial adaptations after conflict. However, also beyond conflict, using a different reinforcement factor than conflict likelihood (as suggested above), this Hebbian learning rule could easily be extended to other paradigms. For example, an asymmetric task-switch cost where the differences in task difficulty are not necessarily defined by (differences in) stimulus- or response-conflict. Alternatively, a recent study by Moeller, Klein, & Nuerk (in press) already extended the implications of the model of Verguts and Notebaert (2008, 2009) to the research domain of implicit learning.

Secondly, we demonstrated how the impact of reward could be investigated, not only by using cues, but also by examining the after-effects of reward presentation on attention and performance. Surprisingly, in the research domain of cognitive control, such reward studies have only been scarcely investigated. For example, to the best of our knowledge, the paradigm of Hickey and colleagues (2010a) was the first to examine this in visual attention, and the paradigm of van Steenbergen and colleagues (2009) in cognitive control. Nevertheless, we believe these rapid modulating effects of reward signals on a trial-to-trial level offer some interesting insights and implications for the being-modulated effect of interest, but also for reward signal processing itself. By demonstrating the absence of a Gratton effect after no-reward trials, we demonstrated how the Gratton effect, also under normal conditions, might be subject to reinforcement learning rules (and the maximization of reward). Therefore we encourage to investigate these direct effects of reward presentation also in other (conflict) tasks. For example, we already piloted the effect of reward on the above-mentioned asymmetric task-switch cost using a similar reward schedule as Chapter 3, again observing an asymmetric task-switch cost after reward, but not after no-reward trials, $F(1,7) = 6.453$, $p > .05$.

Thirdly, in the introduction we argued that a conflict-induced strengthening of associations can be considered as a measure of conflict-induced cognitive stability. However, this strengthening of associations, and the resulting enhanced task focus, might not always ensure the most optimal performance. For example, in a task-switching experiment, the enhanced task-focus after conflict impedes task switching behavior (the Goschke effect). We demonstrated how performance-contingent positive picture presentation could help counteracting this conflict-induced cognitive stability as a function of more efficient task-switching. In a context-specific congruency paradigm (Crump, Gong, & Milliken, 2006), where a context (such as location on the screen) could be largely predictive of the congruency type, people would benefit from a more cognitive flexible mode. If people constantly were to focus on the task alone, they could overlook these contingencies that might otherwise benefit their performance. Therefore, we believe that the context-specific congruency effect (i.e., the observation that the congruency effect is smaller in contexts where incongruent trials are more expected) might be enhanced under a cognitive flexible mode, in contrast to the Gratton effect. Therefore, in a mood study such as the study by van Steenbergen, Band, & Hommel (2010), we could expect an enhanced context-specific congruency effect when in a positive mood, as opposed to a negative mood, in contrast to the pattern expected and observed for the Gratton effect (Kuhbandner & Zehetleitner, 2011; van Steenbergen, Band, & Hommel, 2010).

Fourthly, we illustrated and demonstrated how positive intrinsic reward prediction errors can be enhanced after successfully completing a more difficult trial. Although we suggested how this may impact, or even determine, the subsequent adaptations to conflict on the following trial, this has not yet been investigated. One way to test for this potential relation would be to see how this affective priming effect (as demonstrated in Chapter 6), might correlate with the Gratton effect, independently measured in the same group of participants. This enhanced positive feeling after responding to a more difficult trial could also impact the way we deal with subsequent feedback. Building further on this idea, we re-analyzed the data of Chapter 7, investigating how correct responses, dependent on task difficulty (as determined by task sequence and congruency conditions), could determine perceived picture saliency. In line with the idea that feedback valence processing after correct responses is modulated by task difficulty, this interaction uncovered the anterior cingulate cortex and premotor cortices. Furthermore, dependent on the contingency condition, this led to the differential activation of a memory network, involving the parahippocampal gyri and medial temporal lobe. To see if these activations reflected enhanced attention to those pictures, and hence improved memory (Chun & Turk-Browne, 2007), we ran a follow-up study, in which we independently demonstrated how, indeed, task difficulty (and contingency condition) impacts picture memory in a surprise recall test. Specifically, when contingent on performance, negative pictures (relative to positive pictures) presented after correct responses enhanced parahippocampal activity and picture memory as a positive function of task difficulty. These results suggest that negative, relative to positive, feedback following a difficult trial, might be perceived as more salient than the same pictures following a more easy trial. This is consistent with the idea that a negative stimulus following the rewarding feeling of successfully completing a more difficult task induces a larger reward prediction error. These preliminary results are in line with the affective priming study, also adding to the idea that performance monitoring has an affective component, that can determine the way we perceive feedback and adapt our behavior. Therefore, we believe more paradigms and alternative approaches are needed to further uncover this impact of cognition on emotion, contrasting to the idea that only emotion can bias cognition and not vice versa (e.g., Reeck & Egner, 2011).

Lastly, earlier in this discussion we already suggested how reward studies on cognitive control, independent of the reward implementation in a block-, cue-, item- or performance-specific manner, would benefit from parametrically manipulating reward saliency. This could be done by manipulating its frequency or the type of reward stimuli being used (Okon-Singer, Lichtenstein-Vidne, & Cohen, in press), but also by taking into account individual differences in reward sensitivity. We believe this could be important for investigating the hypothesis that reward, as its saliency increases, does not always garner the same effects. Specifically, while moderate rewards might help reinforce behavior, very salient rewards might set a positive mood signaling that goals have been comfortably achieved, thereby broadening attention (Gable & Harmon-Jones, 2011). In a similar vein, following the ideas of Bijleveld, Custers and Aarts (2012), it would be interesting to manipulate the inter-trial interval between reward and next stimulus presentations, as a deeper processing of reward might have different implications on subsequent behavior.

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NEDERLANDSTALIGE SAMENVATTING: CONFLICT MONITORING EN REINFORCEMENT LEARNING

INLEIDING

In onze dagdagelijkse omgeving dienen we ons constant aan te passen aan conflicterende informatie die het efficiënt uitvoeren van bewegingen, of het vlot maken van beslissingen, dikwijls bemoeilijken. Ondanks het feit dat die obstakels ons regelmatig doen vertragen, of fouten doen maken, zijn we al even vaak verrassend goed in het aanpassen aan die conflicterende situaties. Dit doet vermoeden dat we beschikken over een zeer adaptief mechanisme dat ons helpt ons gedrag bij te sturen en efficiënter keuzes te maken. Dit vermogen dat ons alledaags gedrag kenmerkt wordt vaak naar gerefereerd onder de noemer "cognitieve controle".

Dit vermogen wordt vaak nagegaan aan de hand van conflict taken. Deze paradigmas simuleren dit alledaags conflict door irrelevante informatie te presenteren op een computerscherm, die de reactietijden in het uitvoeren van een taak doen vertragen, of de accuraatheid doen dalen. Specifiek worden in dergelijke taken willekeurig door elkaar congruente of incongruente beurten aangeboden. Een gekend voorbeeld van een conflict taak is de Stroop taak (Stroop, 1935). Daar dient men de kleur te benoemen waarin een woord gepresenteerd wordt. Echter, dit woord kan ook de betekenis van een kleur aannemen. Zo kan men bijvoorbeeld vragen de kleur van het woord "ROOD" of de kleur van het woord "ZWART" te benoemen. Hoewel in beide gevallen het antwoord zwart is, zal het eerste woord (dit is een voorbeeld van een incongruente beurt) dit bemoeilijken omdat de betekenis van het woord een ander antwoord uitlokt (rood), terwijl het tweede woord (dit is een voorbeeld van een congruente beurt) dit net kan versnellen omdat de betekenis van het woord hetzelfde antwoord uitlokt (zwart). In dergelijke taken observeert men steeds een congruentie-effect, zijnde de verschilscore in reactietijden of accuraatheid tussen incongruente en congruente trials. Gratton, Coles en Donchin (1992) toonden daarbij overtuigend aan dat dit congruentie-effect steeds kleiner is, wanneer de vorige trial incongruent is, dan wanneer de vorige trial congruent is. Daarmee was een van de eerste indexeringen van een adaptieve vorm van "cognitieve controle" geboren: het Gratton effect. Dit opende heel wat mogelijkheden, want het Gratton effect stond toe gemakkelijk "cognitieve controle" na te gaan in bijvoorbeeld een fMRI scanner (die beeldvorming van de hersenen toestaat), of een EEG-aparaat (wat de elektrische activiteit in de hersenen kan meten) om zo de relevante mechanismen achter cognitieve controle na te gaan. Precies die ontwikkelingen leidden tot de ontwikkeling van het invloedrijk model van Botvinick, Braver, Barch, Carter, en Cohen (2001): de conflict monitoring theorie.

In hun conflict monitoring theorie stelden Botvinick en collegae voor dat conflict wordt gedetecteerd door de anterieur cingulate cortex (ACC). Aan de hand van een kwantificeerbare maat kan zo bepaald worden wanneer conflict aanwezig is, en kan een signaal doorgestuurd worden naar de dorsolaterale prefrontale cortex (DLPFC) om gedrag aan te passen aan het gesignaliseerde conflict. Op deze manier kan verklaard worden waarom het congruentie-effect steeds kleiner is na incongruente trials, dan na congruente trials. Namelijk, op incongruente trials wordt conflict gedetecteerd, en dit staat toe om gedrag aan te passen door het verwerken van taakrelevante eigenschappen te versterken. Echter, deze implementatie blijft eerder vaag en kan bijgevolg niet alle fenomenen verklaren. Zo is het bijvoorbeeld onduidelijk hoe de "conflict monitoring theorie" weet waar welke taak(-eigenschappen) moeten aangepast worden. Bovendien kan deze theorie niet instaan voor enkele recente bevindingen die aantonen dat conflict adaptatie, oftewel het Gratton effect, op een itemspecifiek niveau werken, eerder dan op een algemeen taakniveau.

Om cognitieve controle processen beter te kunnen modelleren en begrijpen, geloven we dat een nieuwe invalshoek vanuit het onderzoeksdomein rond reinforcement learning gunstig kan zijn. Reinforcement learning begint reeds bij de eerste ontdekkingen van vroege behavioristen zoals Pavlov, Skinner, en Watson, maar groeide de laatste decennia exponentieel uit tot een multidisciplinair onderzoeksgebied. In dit doctoraat willen we nagaan of deze recente ontwikkelingen, maar ook enkele reeds oudere onderzoeksideeën uit de reinforcement learning-theorieën kunnen bijdragen tot het beter begrijpen van conflict adaptaties.

Als eerste invalshoek willen we nagaan hoe Hebbiaans leren een alternatief kan bieden voor het modelleren van conflictprocessen en meer specifiek, het Gratton effect. Hebbiaans leren wordt vaak samengevat door de leuze: *what fires together, wires together*. Eenvoudig samengevat betekent dit dat wanneer twee neuronen op dezelfde tijd hun actiepotentiaal zenden, ze na verloop van tijd verbindingen met elkaar vormen. In de lijn van dit idee is een recent model ontwikkeld aan onze vakgroep dat het Gratton effect op die manier verklaart (Verguts & Notebaert, 2008, 2009). Meer specifiek wordt er gesteld dat wanneer conflict gedetecteerd wordt, er een arousal signaal door de hersenen wordt gestuurd die alle actieve associaties versterkt door een Hebbiaans leerprincipe. Desondanks de algemeenheid van deze leerregel, leidt ze echter tot heel specifieke predicties. Zo kunnen we gaan verwachten dat wanneer actieve verbindingen versterkt worden, ze ook taak-irrelevante prominente eigenschappen mee kunnen versterken. Evenzeer kunnen we voorspellen dat adaptaties na conflict op een item- en effectorspecifiek niveau zullen gaan werken. Deze voorspellingen gingen we na in Studies 1 en 3.

Volgens reinforcement learning-theorieën wordt steeds geleerd in functie van het maximaliseren van een bekrachtiging. Dit kan een beloning zijn in vorm van voedsel, maar ook geld, of meer vage doelen, zoals het bereiken van een succesvolle carrière. In een eenvoudige reactietijdentaak kan dit zelf de (minieme) zelfvoldoening zijn na het succesvol beantwoorden van een beurt op de taak (Satterthwaithe et al., 2012). Daarom hebben we ook experimenten opgezet waarin we nagingen of beloning na correcte respons (of straf na te trage/foutieve respons) invloed kon hebben op het Gratton effect. Daarbij waren we ook benieuwd naar interindividuele verschillen in belonings- en strafgevoeligheid en hebben we simultaan ook steeds de BIS/BASvragenlijsten afgenomen, die verondersteld worden straf- en beloningsgevoeligheid te meten. Deze experimenten werden afgenomen in Studies 2, 3, en 4.

Reinforcement learning-theorieën doen ook uitspraken over hoe beloning wordt verwerkt of ervaren. Er wordt hierbij gesteld dat het ervaren van een beloning steeds een verschil is tussen de verwachtte beloning en de effectief verkregen beloning. Hoe groter het verschil tussen die twee is, hoe groter onze *reward prediction error* is. Een recent model die het werken van de ACC wil modelleren, voorspelt dat de ACC precies zo'n berekeningen maakt en dat deze dat ook doet in cognitieve taken, waar geen expliciete beloning wordt uitgedeeld. Bijvoorbeeld, wanneer we een congruente beurt, versus een incongruente beurt, te zien krijgen, weten we dat onze *outcome expectancy*, oftewel onze verwachting dat we accuraat op deze beurt zullen scoren, groter is bij congruente, dan bij incongruente. Daarom kan ook worden voorspeld dat bij het zien van incongruente beurt meer negatief affect zal worden ervaren (Dreisbach & Fischer, 2012), dan bij het zien van een congruente beurt. Echter, wanneer dan ook effectief goed geantwoord wordt op deze stimulus, kan men gaan verwachten - in de filosofie van *reward prediction errrors* - dat deze ervaring omkeert. Net omdat de *outcome expectancy* lager was bij incongruente, dan bij congruente stimuli, kan het correct beantwoorden van deze beurt als meer positief of "belonend" ervaren worden. Deze voorspelling werd nagegaan in Studie 5.

Een probleem waar elk reinforcement learning-algorithme mee te kampen heeft, is het probleem van exploratie versus exploitatie, of cognitieve flexibiliteit versus stabiliteit. Een eeuwenoude wet binnen bekrachtigingleren stelt dat wanneer iets gevolgd wordt door een beloning, deze de daartoe leidende acties zal versterken (Thorndike, 1911). Op die manier is het dan ook verstandig om te exploiteren (i.e., uit te buiten) wat reeds geweten is. Echter, omgevingen veranderen, en soms is de beste oplossing van gisteren niet meer de beste oplossing van vandaag. Daarom is het belangrijk steeds uit te kijken voor andere mogelijkheden en dus te exploreren. Hoe die balans gemaakt wordt tussen exploreren en exploiteren in ons alledaags leven is vaak nog onduidelijk. Een onderzoeksrichting die reeds eerste inzichten biedt in wat ons daarin kan sturen is onderzoek naar positief en negatief affect. Heel algemeen wordt daarbij vooronderstelt, dat een algemeen positief gevoel er vaak toe leidt meer te gaan exploreren, terwijl een algemeen negatief gevoel er meer zal toe leiden meer te exploiteren. Binnen het onderzoek rond conflict verwerking kunnen we het Gratton effect zien als een maat van exploitatie of conflictgeïnduceerde cognitieve stabiliteit. Dit pas binnen het idee dat na conflict, verbindingen worden versterkt die tot het succesvol beantwoorden van die incongruente beurt leidden. Een stap verder, kunnen we dan ook verwachten, dat na een incongruente beurt, het moeilijker zou zijn om van taak te verwisselen, dan na een congruente beurt. Dit is ook reeds aangetoond. Goschke (2000) toonde reeds aan dat in een taak-wisselexperiment, waar het steeds de bedoeling is willekeurig van taak te moeten wisselen, dit moeilijker verloopt wanneer je net een incongruente beurt beantwoorde, dan wanneer de vorige beurt een congruente was. Dit zullen we van hier af aan het Goschke effect noemen, en dit zal ook de indexering zijn van conflict adaptaties die we zullen hanteren in studies 2 en 6. Specifiek zullen we nagaan in studie 6 of het Goschke effect kan beïnvloed worden door positief en negatief affect, en of een eventuele link tussen het affect en het taakgedrag daarin een rol speelt.

STUDIE 1: CONFLICT ADAPTATIE IS EFFECTORSPECIFIEK

Het doel van deze eerste studie was om na te gaan of conflict adaptatie, oftewel het Gratton effect, ook te zien zou zijn wanneer men afwisselend een taak met handen of voeten diende uit te voeren. Hierbij voorspelden we dat, als het inderdaad zo is dat conflict adaptatie gebeurd door het versterken van actieve verbindingen, stimulusrespons verbindingen die actief waren op de vorige beurt meer versterkt zouden worden dan alternatieve stimulusrespons associaties. In andere woorden verwachtten we dus enkel een Gratton effect als de vorige en huidige beurt met dezelfde effectoren dienden uitgevoerd te worden. Effectief, we vonden enkel een Gratton effect van handen naar handen, of voeten naar voeten, maar niet van handen naar voeten of voeten naar handen. Dit is consistent met het idee dat het Gratton effect effectorspecifiek is. Om andere kleine verschillen tussen het toewijzen van de taak aan handen en/of voeten in rekening te nemen, werd ook een controle-experiment uitgevoerd waar beide responsmappings met de handen werden uitgevoerd. Daar vonden we zowel binnen als tussen verschillende responsmappings een Gratton effect.

STUDIE 2: BELONING MODULEERT ADAPTATIES NA CONFLICT

In deze tweede studie gingen we na of het (sporadisch) aanbieden van beloningssignalen het Gratton en Goschke effect zouden beïnvloeden. Hierbij veronderstelden we dat als het Gratton en Goschke effect effectief leereffecten zijn die hoofdzakelijk bestaan uit het versterken van associaties, dan zou het aanbieden van een beloning enkel dit versterken van associaties moeten promoten. Hiertoe combineerden we een eenvoudige conflict taak in een eerste experiment, en twee conflicttaken in een tweede experiment, met het aanbieden van beloningssignalen om de invloed van die beloningssignalen op respectievelijk het Gratton en Goschke effect na te gaan. Beide experimenten toonden aan dat de adaptaties na conflict stand hielden wanneer beloning werd uitgeleverd, maar niet wanneer er geen beloning werd getoond. Twee controle-experimenten toonden aan dat dit effect niet te wijten was aan het louter aanbieden van een sporadische visuele stimulus. Daarenboven werd ook een correlatie aangetoond tussen de BAS beloningsgevoeligheid vragenlijsten en de modulatie van het Gratton en Goschke effect. Deze bevindingen tonen aan dat adaptaties wel degelijk kunnen versterkt worden na beloning, en, opmerkelijk, dat het uitblijven van een beloning in een beloningscontext zelf de waarde van het correct beantwoorden kan wegnemen zodat conflict adaptatie op de volgende beurt uitblijft.

STUDIE 3: BELONING MODULEERT CONTEXTSPECIFIEKE ADAPTATIES NA CONFLICT

We toonden reeds aan dat conflict adaptatie contextspecifiek is in Studie 1 en dat beloning conflict adaptatie kan versterken in Studie 2. In deze derde studie was het de bedoeling om beide bevindingen samen na te gaan en te zien of conflict adaptatie wordt versterkt na beloning op een contextspecifieke manier. Daartoe hebben we ons laten inspireren op een paradigma van Hickey, Chelazzi, & Theeuwes (2010) waarbij ze aantoonden dat in een visuele zoektaak een hoge beloning de aandacht naar een taakirrelevante kleur kan doen versterken als dit bijdroeg tot het sneller uitvoeren van de taak, terwijl een lage beloning eerder de aandacht naar een alternatieve afleidende kleur (die de taakuitvoering vertraagt) doet versterken. Door deze taak te combineren met een conflicttaak kunnen we nagaan of deze invloed van beloning op taakirrelevante kleuren ook een weerslag zou hebben op conflict adaptatie. In een eerste experiment toonden we aan dat, zonder beloningsmanipulatie, we reeds een invloed vinden van kleurherhaling/afwisseling op conflict adaptatie. Conflict adaptatie werd waargenomen wanneer kleur, als contextkenmerk, zich herhaalde, maar niet wanneer de context wisselde. In een tweede en derde experiment werd daar lage en hoge beloning aan toegevoegd. In de lijn met het patroon van Hickey en collegae (2010) vonden we dat na hoge beloning opnieuw conflict adaptatie werd waargenomen, maar enkel op context repetities. Terwijl na lage beloning er enkel een Gratton effect werd waargenomen op context alternaties.

STUDIE 4: STRAF MODULEERT ADAPTATIES NA CONFLICT, AFHANKELIJK VAN STRAF GEVOELIGHEID

In deze vierde studie was het de bedoeling om na te gaan of ook het straffen van te trage of foutieve antwoorden als leersignaal kon gelden om het Gratton effect te versterken. In een studie van Stürmer, Nigbur, Schacht, en Sommer (2011) werd dit reeds nagegaan. Zij vonden dat enkel na beloning, maar niet na straf, het Gratton effect groter was. Na straf vertraagden de proefpersonen enkel. Echter, geïnspireerd door de literatuur dat straf vaak prominenter is dan beloning, vermoeden we dat de strafsignalen in de studie van Stürmer en collegae (2011) de aandacht wegtrokken van de taak en daarom de reactietijden verhoogden. We hebben daarom de BIS scores als een maat van strafgevoeligheid mee in rekening genomen en voorspelden hierbij dat straf inderdaad gedrag zal doen vertragen, wanneer mensen zeer gevoelig zijn aan straf, maar dat voor normaal of laag strafgevoelige mensen straf zou moeten helpen om taakprestatie, in dit geval het Gratton effect, te verbeteren. Dit was ook precies wat we observeerden. Straf versterkte het Gratton effect voor de laag strafgevoelige mensen, maar vertraagde reactietijden voor hoog strafgevoelige mensen.

STUDIE 5: KAN HET CORRECT BEANTWOORDEN VAN CONFLICT BELONEND ZIJN?

In de inleiding stelden we voor dat wanneer we een relatief lage verwachting hebben over onze accuraatheidscores op een incongruente beurt dit als negatief wordt ervaren bij het zien van die beurt, maar als positief (of op zijn minst relatief positiever dan na congruente beurten), wanneer we die correct beantwoorden. Om dit na te gaan maakten we gebruik van een affectief priming paradigma. In zo'n paradigma is het de bedoeling dat een bepaalde gebeurtenis of stimulus geldt als "prime" die dan het beoordelen van affectieve woorden zal beïnvloeden. Bijvoorbeeld, wanneer mensen zeer graag roken zal men na het zien van een prent van een sigaret sneller zijn om een positief woord als positief te classificeren, dan een negatief woord als negatief, terwijl we bij anti-rokers een omgekeerd patroon zouden verwachten. Dit is omdat de prent van een sigaret reeds een gevoel uitlokt dat het lezen/classificeren van woorden die datzelfde gevoel uitlokken kan versnellen, of met een ander gevoel vertragen. Dit zette onderzoekers Dreisbach en Fischer (2012) er toe aan om dit na te gaan na het zien van congruente of incongruente stimuli. Zij toonden daarbij overtuigend aan dat na incongruente stimuli, mensen relatief sneller zijn in het benoemen van de negatieve woorden, dan na congruente stimuli, wanneer ze relatief sneller zijn in het benoemen van positieve woorden. In een eerste experiment hebben we dit effect gerepliceerd. Echter, in een tweede en derde experiment, tonen we vervolgens aan, dat wanneer men ook correct diende te antwoorden op deze conflict stimuli, men relatief sneller was voor positieve woorden, dan voor negatieve woorden na incongruente beurten, ten opzichte van congruente beurten. In een vierde experiment, een controle-experiment, tonen we ook aan dat dit effect niet voor alle vormen van taakmoeilijkheid geldt.

STUDIE 6: AFFECTIEVE MODULATIES VAN CONFLICT ADAPTATIE EN DE ROL VAN TAAK RELEVANTIE

In deze zesde en laatste studie wilden we iets bijdragen aan het debat dat positieve emoties cognitieve flexibiliteit promoten en negatieve cognitieve stabiliteit. Daarvoor hanteerden we het Goschke effect als maat van conflictgeïnduceerde cognitieve stabiliteit en waren we vooral belangrijk hoe diens modulatie door affect zou bepaald worden door het al dan niet taakrelevant zijn van de affectieve stimuli. Daarom hebben we twee condities opgezet waar proefpersonen willekeurig konden aan toegewezen worden. In de ene conditie werd proefpersonen verteld dat de negatieve en positieve prenten die steeds tussen de beurten door gepresenteerd zouden worden totaal ongerelateerd waren aan hun taakgedrag. In een andere conditie, echter, werd de proefpersonen verteld, en dit was ook zo, dat positieve en negatieve prenten enkel op correcte antwoorden zouden volgen. Bovendien werd in beide condities meegegeven dat het zien van positieve prenten hen 10 dollarcent zou opleveren. Dit wil dus zeggen dat enkel in de taakgerelateerde conditie het foutief beantwoorden van een beurt kon leiden tot het uitblijven van een positieve prent, en dus 10 dollarcent. Onze resultaten toonden aan dat enkel in de taakgerelateerde conditie positieve prenten inderdaad ervoor zorgen dat het Goschke effect verdween, en zo cognitieve flexibiliteit en exploratie promoten, terwijl in de taakongerelateerde conditie dit effect eerder omkeerde.

Bovendien werd in dit experiment ook beeldvorming van de hersenen afgenomen aan de hand van functionele MRI (Magnetic Resonance Imaging). Dit stond ons toe zowel een beeld te vormen van het Goschke effect, als een beeld van hoe affectieve prenten dit effect beïnvloeden, afhankelijk van de taakrelevantie-conditie. Hierbij merkten we op dat hoewel het Goschke effect vooral gereflecteerd werd in een verhoogde rekrutering van de dorso-laterale prefrontale cortex en het striatum, de affectieve modulatie van dit effect voor tot stand kwam door een modulatie van de ventro-mediale prefrontale cortex en de posterieur cingulate cortex.

Bovendien werd ook gekeken hoe het waarnemen van de affectiviteit van de prenten, beïnvloed kon zijn door de taakrelevantie van de conditie. Daarbij vonden we activatie terug in de rechter inferieur parietale lobule.

BESLUIT

Dit doctoraat was er toe opgezet om de rol van reinforcement learning bij cognitieve controle, meer specifiek conflict adaptaties na te gaan. We hebben daarbij aangetoond hoe, inderdaad, conflict adaptatie effector-, en contextspecifiek is. Bovendien hebben we bewezen hoe conflict adaptatie mede bepaald kan worden door straf- en beloningssignalen en hoe belonings- en strafgevoeligheid daarin een rol kunnen spelen. Vervolgens demonstreerden we hoe het succesvol beantwoorden van conflict op zich reeds een positief gevoel met zich mee kan brengen. Tenslotte toonden we aan dat affect conflict adaptatie beïnvloed, afhankelijk van wat affect over taakgedrag zegt, in zowel reactietijden als hersenactivaties. We zijn er van overtuigd dat deze resultaten er kunnen toe bijdragen om conflict adaptatie vanuit een andere invalshoek te interpreteren, en een inspiratie kunnen vormen voor verder onderzoek die cognitieve controle in termen van leermechanismen wil nagaan, eerder dan die aan een homunculus te moeten toeschrijven.

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