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FACULTEIT PSYCHOLOGIE EN
PEDAGOGISCHE WETENSCHAPPEN

Reactive and proactive cognitive control

Wout Duthoo

Promotor: Prof. Dr. Wim Notebaert

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

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ACKNOWLEDGEMENTS

Finally, I've made it! The end of the journey through the magical land that is Experimental Psychology, where every millisecond counts and the human soul can be skilfully discussed in terms that no human soul can readily understand, now clearly comes into sight. Even though this acknowledgements section is paradoxically placed at the beginning of this book, it was written right on the home stretch. But this final exercise turned out to be quite a nice one: Looking back at three and a half marvellous years of science and fun, and thanking all the people that made it such a stimulating and joyful ride.

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To close this section, before it exceeds the length of any of the following chapters, I can truly say I saved the best for last. Annelies, it has become hard to realize that I only know you for three years or so, because being together with you just feels so incredibly right: you are the single most original, pure and fun human being I have ever met. Thank you so much for being around!

Wout,

April 8, 2013

CHAPTER 1
GENERAL INTRODUCTION

Cognitive psychology is a beautiful, never-ending enterprise. To lose yourself in the details of the mind, in phenomena that last only a few milliseconds and then dissolve into the great melting pot of consciousness without leaving a trace, it's like trying to guess the number and function of the cogs of a tiny machine encased in a steel box that has been welded shut, just by shaking it. There's a warning sticker on the outside of the mind: Warranty void if opened. No user-serviceable parts inside.

Yes, this is the life! This is the real deal; it's like getting a chemistry set for Christmas, but someone forgot to include the instructions.

- Paul Verhaeghen, 'Omega Minor', pp. 41.

INTRODUCTION

Psychology's main theoretical paradigm has always built on and/or struggled with the dichotomy of, on the one hand, controlled and voluntary higher cognitive processes, and, on the other hand, automatic and stimulus-driven processes. In his seminal work, William James (1890) already speculated how attention could be voluntary and active, or rather reflexive and passive. Not long after James, Watson's behaviourism denied the use of higher cognitive constructs and aimed to explain behaviour in observable, purely biological terms captured by stimulus-response associations. However, from the second half of the twentieth century, a cognitive revolution in psychology shifted back the pendulum and embraced the study of higher cognitive functioning again. Influential theories were introduced about a broad range of mental processes, such as selective attention (Broadbent, 1958), working memory (Baddeley, 1986), and reasoning (Johnson-Laird, 1983), which were indirectly put to the test by ingenious reaction time experiments (Sternberg, 1969) and further understood through connectionist modelling (e.g., Cohen, Dunbar, & McClelland, 1990). Finally, with the steep and remarkable upsurge of neuroscientific methods in psychology, cognitive neuroscience introduced a renewed interest in the biological basis of behaviour, relating behaviour to neural activity and brain functioning. Nowadays, there is a growing consensus that the traditional analysis of cognition can be substantially boosted by knowing how cognition is implemented in the brain. Moreover, neural markers of both stimulus-driven processes and higher-order voluntary processes have been found, thereby weakening a strict dichotomy. This leaves a field that is characterized by a blend of cognitive, descriptive frameworks and neural network implementations that are inspiring and constraining each other at the theoretical level.

Analogous to this brief historical overview, the study of *cognitive control* has witnessed similar shifts in focus on the relative role of higher mental processes in explaining behaviour. Cognitive control, a young domain of study in psychology, is an umbrella term that refers to the flexible and adaptive regulation of behaviour in line with our intentions, goals or plans in the face of conflict. It encompasses, among other things, selective attention, inhibition, working memory and task switching. These higher mental processes were originally captured in purely descriptive theories (Shiffrin & Schneider, 1977; Norman & Shallice, 1980), and tested in experiments that stressed the voluntary and strategic nature of the control processes involved (e.g., Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984; Gratton, Coles, & Donchin, 1992). Yet, research on cognitive control saw an enormous boost with the formulation of the conflict monitoring theory (CMT; Botvinick, Braver, Barch, Carter, & Cohen, 2001), that offered an intriguing view of how the cognitive system 'knows' when to increase control and how this is implemented in the brain. Briefly, CMT posits that the detection of cognitive conflict, conceptualized as simultaneously active and incompatible response tendencies, triggers a stronger focus on task-relevant information. This 'reactive' control regulation is superficially similar to how behaviourists described 'reflexive' behaviours in reaction to stimulation. A wealth of studies has further pinpointed the exact neural underpinnings of this conflict control loop. Later theorizing also extended the model with associative, stimulus-response learning algorithms (Verguts & Notebaert, 2008; 2009). As associative learning generally has the connotation of being automatic, fast and effortless, the adaptation-by-binding model exemplifies the shift in the view of control as being voluntary, relatively slow and effortful. The oxymoronic term 'automatic control' was first coined by Jacoby, Lindsay, Hessels, 2003, and has since then been increasingly influential in theorizing on cognitive control (see Bugg and Crump, 2012, for a review).

Only recently, research on cognitive control was again further expanded by the investigation of how *expectancies* also modulate behaviour in pursuing our actions or goals in a 'proactive' fashion (Braver, 2012; Braver, Gray, & Burgess, 2007), referring back to the strategic and voluntary control of attention (Logan & Zbrodoff, 1979; Gratton et al., 1992). Intriguingly, whereas the idea of 'expectancy' as a distinct construct and cause of behaviour was seen by behaviourists as a prime example of redundant theorizing of higher mental processes in cognitive psychology (Umbach et al., 2012), it has lately witnessed a growing interest in many fields of psychology. Predictive representations of visual information have been shown to guide and prepare the brain for upcoming stimulation (Bar, 2007), and recent modelling work (Alexander & Brown, 2011; Silvetti, Seurinck, & Verguts, 2011) has stressed the role of learning on the basis of prediction-driven outcomes in optimizing behaviour, contingent on the discovery of the neural mechanisms behind prediction errors (Schultz, 1998; see den Ouden, Kok, & de Lange, 2012, for a review). Contrary to reactive adjustments in cognitive control, as captured by the CMT, the extent to which proactive, expectancy-based control adjustments regulate behaviour is far less understood.

The present dissertation aimed to further contribute to the expanding research on cognitive control, by playing out reactive, conflict-driven and proactive, expectancy-driven control adjustments against each other. Before going deeper into the aims and specific research questions of the thesis, this chapter first sets the stage by introducing cognitive control and the paradigms that have been applied to study it. Next, the congruency sequence effect, a hallmark in the study of cognitive control that also plays a central role in many of the empirical chapters, is shortly reviewed. Finally, the distinction between and specific evidence in favour of reactive and proactive control is discussed more extensively.

COGNITIVE CONTROL

In today's overly busy society, we are continuously bombarded by temptations that we need to resist. Social network and entertainment sites beg for our attention during working hours, and our preferred but unhealthy snacks and drinks are readily available around every corner. This requires us more than ever to orchestrate and direct behaviour and attention according to internal goals or external task demands – so-called cognitive control. In their pioneering work on cognitive control, Norman and Shallice (1980) identified and grouped situations that typically trigger the call for such cognitive control processes. Among other things, they highlighted situations that require us to overcome habitual, prepotent responses, situations where new responses have to be learned that are not well-rehearsed, or situations in which errors are likely to occur or have to be corrected. Classic examples refer to resisting that tasty snack after deciding to stick to a diet, or overcoming rush hour traffic during a first driving class. Regulating behaviour as such clearly suggests an intentional and effortful control process, yet recent evidence has shown that control processes can equally well be implemented unintentionally or unconsciously (Sumner et al., 2007; Kunde, Reuss, & Kiesel, 2012), implying that they are an emergent property of the cognitive system striving for optimal performance (Ridderinkhof, Forstmann, Wylie, Burle, & van den Wildenberg, 2010). Regardless of the underlying intentionality, cognitive control thus entails inhibiting prepotent responses and/or focussing attention on task-relevant information in order to comply with task demands or intentions.

The usefulness of such functions may be most dramatically witnessed in cases that they are disturbed by neurological damage. Neuroscientific findings have consistently linked instances of executive control to the workings of the prefrontal cortex (Miller & Cohen, 2001). In so-called frontal lobe patients suffering from severe prefrontal cortex damage, loss of these functions led to difficulties with planning, inhibiting overlearned responses and executing tasks in a goal-directed manner (Damasio, 1994; Shallice & Burgess, 1991). As a particularly striking example, Lhermitte (1983) described frontal lobe patients who could no longer resist the urge to act upon objects or cues within their visual field, even when these actions were contextually inappropriate – so-called utilization behaviour. The mere sight of a toothbrush, for example, would make these patients immediately grab the toothbrush and start using it, apparently in the absence of the intention to do so. This shows that stimuli can evoke the tendency to perform the actions that were habitually associated to them. In order not to succumb to these automatic response tendencies, executive control is necessary. Even though these patient studies have been insightful in uncovering the role of the prefrontal cortex in cognition, the bulk of the research has focused on gaining better insights into the umbrella term that is cognitive control, by studying selective attention, response inhibition and task switching, as well as their neural correlates, in controlled experiments on healthy volunteers.

PARADIGMS OF COGNITIVE CONTROL

In order to measure how people are able to resist temptations or to overcome strong or habitual responses in favour of a more controlled response, experimental psychologists have created laboratory tasks that aim to mimic such conflicting situations. So-called stimulus-response compatibility or *congruency tasks* manipulate the dimensional overlap (e.g., Kornblum, Hasbroucq, & Osman, 1990) between the task-relevant stimulus dimension, the task-irrelevant stimulus dimension and the response dimension as to evoke ‘conflict’ – simultaneously active, incompatible neural representations (see Egner, 2008, for a schematic overview). As a prime example, the Stroop task (Stroop, 1935; see MacLeod, 1991, for a review) requires participants to simply respond to the colour in which a stimulus is presented. However, by presenting colour words as stimuli and manipulating the compatibility between the task-relevant (colour) and task-irrelevant (word) dimension, congruent (the word ‘BLUE’ printed in blue) and incongruent (the word ‘BLUE’ printed in yellow) stimuli are created. Since word reading is an overlearned, prepotent response, incongruent trials evoke conflict, and cognitive control is needed to comply with task instructions and respond to the relevant colour dimension. In a similar vein, the flanker task (Eriksen & Eriksen, 1974) instructs participants to respond to the central target that is either flanked by compatible (> > >) or incompatible (> < >) flankers. In both congruency tasks, the difference in reaction times (RTs) and performance errors (PEs) is taken as a measure of response conflict - the *congruency effect*. Variations in the size of the congruency effect are assumed to reflect fluctuating cognitive control. This approach to studying cognitive control was central to the majority of the chapters included in this dissertation.

Whereas congruency tasks measure selective attention and control over prepotent responses, task switching paradigms have been applied to elucidate how people flexibly shift between cognitive tasks. In such *task switching* experiments, participants must overcome their tendency to keep repeating the same task and flexibly switch between two or more tasks (see Kiesel et al., 2010, for a review). Especially when several tasks are to be performed on the same class of targets, cognitive control is needed to activate and maintain the appropriate task-set, or inhibit a previously appropriate one, as to keep performance in line with instructions. Therefore, the difference in RTs and PEs between trials in which participants switched to the other task and trials in which participants repeated the same task – the ubiquitous *switch cost* – is taken as a measure of task switching performance. Even when task switch trials are predictable (the alternating runs paradigm; Rogers & Monsell, 1995), cued in advance (Meiran, 1996) or voluntarily chosen (Arrington & Logan, 2004), a residual switch cost remains. Still, variations in the size of the switch cost are also assumed to reflect variations in cognitive control. This approach was followed in Chapter 4.

CONGRUENCY SEQUENCE EFFECTS

As has been indicated above, fluctuations in the size of the congruency effect in conflict tasks are assumed to provide a direct window onto attentional adjustments in cognitive control. The congruency sequence effect (CSE; also termed conflict adaptation or *Gratton* effect) refers to the observation that the congruency effect is typically smaller after an incongruent than after a congruent trial (see Egner, 2007, for a review). These sequential adjustments have inspired much empirical and theoretical work – and they also lie at the core of most of the chapters in this dissertation. The CSE is a prime observation underlying the Conflict

Monitoring Theory (CMT) of Botvinick and colleagues (2001), which substantially boosted and dominated the research on cognitive control over the last decade. In this framework, CSEs are thought to reflect conflict-triggered enhanced attention to task-relevant information in order to maintain goal-directed behaviour – so-called *conflict adaptation* (Botvinick, Cohen, & Carter, 2004). In short, CMT assumes that the processing stream is continuously monitored for the occurrence of conflict, conceptualized as simultaneously active incompatible neural representations (Botvinick et al., 2001). Contingent upon the detection of conflict by the monitoring system, supposedly residing in the anterior cingulate cortex (ACC; Jones, Cho, Nystrom, Cohen, & Braver, 2002), control is up-regulated. This upregulation is thought to be implemented by the dorsolateral prefrontal cortex (Egner & Hirsch, 2005a; Kerns et al., 2004), presumably through cortical amplification of task-relevant information (Egner & Hirsch, 2005b).

According to the *conflict monitoring account*, the CSE reflects the detection of conflict on the previous incongruent trial and subsequently triggered enhanced attentional task-relevant focus, leading to reduced congruency effects on the next trial. However, alternative explanations have been postulated in which CSEs have nothing to do with cognitive control, but rather derive from simple event-based learning. One such alternative builds from the notion of *feature binding* (Hommel, Proctor, & Vu, 2004; Mayr, Awy, & Laurey, 2003), proposing that CSEs relate to the costs of partial feature repetitions. This debate has spawned a series of studies that aimed to disentangle influences from feature integration and conflict adaptation, leading to the conclusion that it seems unlikely that all of the CSE is due to such feature binding (Akçay & Hazeltine, 2001; Kerns et al., 2004; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Notebaert & Verguts, 2007; Ullsperger, Bylsma, & Botvinick, 2005).

A second major debate – to which several of the chapters in this dissertation are dedicated – can be identified *within* the perspective that CSEs reflect attentional modulation rather than side-effects of more basic episodic memory processes. When the CSEs were first reported by Gratton, Coles and Donchin (1992), the authors interpreted these as reflecting strategic attentional adjustments based on participants’ expectancy regarding the nature of the upcoming trial – irrespective of conflict. Importantly, and somewhat counterintuitively, these authors further assumed that participants do not match these expectancies to the objective probabilities of the stimuli’s occurrences, but are biased towards expecting repeated stimulus conditions from the previous to the next trial. Even though evidence for this *repetition expectancy* account is rather limited (Gratton et al., 1992), it poses the interesting theoretical possibility that attentional adjustments can also be triggered proactively – based on participants’ expectancies, rather than (or complementing) those adjustments that are triggered in a reactive fashion – by conflict on the previous or recent trials. In the following section, this distinction is further discussed, and the evidence in favour of both is summarized. Next to the chapters on conflict and congruency tasks, *Chapter 4* considered the effect of expectancy-based preparation on the task switch cost. Therefore, the overview of reactive and proactive control is extended to the task switching domain.

Box 1 – Experimental Tasks

In this dissertation, three tasks have been employed. First and foremost, we adopted the classic *colour-word Stroop conflict task* (Stroop, 1935). In this task, responding to the task-relevant colour of the colour word is either facilitated or hindered by the meaning of the task-irrelevant colour word meaning, creating congruent (C) and incongruent (I) trials, respectively. Given that overlap in stimulus features from one trial to the next is known to affect performance (Hommel et al., 2004), we designed an eight-colour Stroop task, in which features never repeated across three consecutive trials. The sequence below depicts a C-C-I-I-C transition.

In Chapter 6, we applied a *gender face-word Stroop conflict task* (Egner et al., 2008). In this task, responding to the task-relevant gender of the face is either facilitated or hindered by the congruent or incongruent gender label superimposed on the face. Rather than precluding certain trial types, we kept associative effects and feature overlap constant across trial types. The sequence below depicts a C-C-I-I-C transition.

In Chapter 4, we applied a *magnitude/parity task switching paradigm*. In the parity task, the target number is judged to be either even or odd, whereas in the magnitude task, the target number is judged to be either smaller or larger than five. The colour of the target indicated whether a magnitude (yellow) or parity (blue) judgement was required. All targets were equally often presented in both target colours. The sequence below depicts an M-M-P-P-M transition.

REACTIVE VERSUS PROACTIVE COGNITIVE CONTROL

With considerable practice, most of human behaviour flows effortlessly and flawlessly, seemingly without much of intentional control. Luckily, a football player does not have to carefully plan his movements each and every time he is heading full speed towards the goal. In a similar vein, biking home after work goes without much thinking about how to get there. That is, until a distracted pedestrian suddenly pops up in front of our bike, and we are just in time to pull the brakes. For the rest of the trip, we will keep a closer eye on the road than usual, so as to prevent similar situations. These kinds of *reactive* control adjustments commonly come into play fast when needed, implying a monitor that readjusts behaviour whenever necessary. Indeed, when the traffic light turns red, we usually slow down well in time. Yet, we are equally able to anticipate the light turning green again, and prepare to pull up faster than the other cars around us. In a similar vein, professional cyclists set out to explore the track in advance, in order to foresee potential pitfalls and strive for an optimal performance. This shows that we can also steer and control our attention and actions in anticipation of a future event. In other words, *proactive* control adjustments can also be called upon to optimize our behaviour to our current goals, plans or desires.

SELECTIVE ATTENTION

In the slipstream of the influential conflict monitoring theory (Botvinick et al., 2001) described above, research on cognitive control has focused predominantly on adaptive adjustments in selective attention that are triggered reactively in a response to conflict. Indeed, this has been the major framework in which not only subsequent behavioural work (see Egner, 2007, for a review), but also most of the fMRI (e.g., Botvinick et al., 2004; Egner & Hirsch, 2005a; 2005b; Kerns et al., 2004; Ridderinkhof et al., 2010), and EEG studies (e.g., Larson, Clayson, & Baldwin, 2012; Larson, Kaufman, & Perlstein 2009; Donohue, Liotti, Perez III, & Woldorff, 2012; Stürmer, Leuthold, Soetens, Schröter, & Sommer., 2002) have been framed.

Neuroimaging studies have, for example, evidenced how increased ACC activity on incongruent trials correlated with subsequent activity in the DLPFC (Kerns et al., 2004) and the concomitant reduction of the experienced conflict on the next trial. The better temporal resolution of EEG has, for example, allowed researchers to show how increased response capture (premotoric activity for the incorrect response) by the irrelevant stimulus dimension is reduced by previous conflict (Stürmer et al., 2002).

Part of the appeal of the CMT lies in its elegant solution for the elusive homunculus problem: by making performance adjustments contingent on a quantifiable and neurologically plausible measure of conflict, CMT precluded the necessity of an unspecified intelligent agent (i.e., a 'little man' or homunculus) that knows *when* control adjustments are necessary. Extending on this framework, the *adaptation-by-binding* account by Verguts & Notebaert (2009) suggested an associative learning model that not only knows *when* but also *where* control needs to be upregulated. More specifically, conflict in the model leads to a strengthening of all currently active representations. Given that these active representations are typically task-relevant, conflict detection on the previous trial will thus strengthen task-relevant associations, reflected in a reduced congruency effect on the next trial (i.e., a CSE). To further its biological basis, the model assigns a critical role to noradenalin (NA) as the neuromodulatory force driving the adaptation, even though evidence for NA being the crucial neurotransmitter is rather scarce (see, e.g., van Bochhove, Vanderhaegen, Notebaert, & Verguts, 2012; Duthoo et al., submitted, for evidence in favour of dopamine as a crucial neurotransmitter in bringing about the CSE). Finally, the model has also been proven useful in explaining instances of cognitive control in the task switching domain, providing a convincing account for the finding of an enhanced switch cost following incongruent trials (Braem, Roggeman, Verguts, & Notebaert, 2012), and, more general, the idea that part of the switch cost can be related to task-set inertia due to previous stimulus-task set bindings (Waszak, Hommel, & Allport, 2003).

However, there is also some evidence that attentional adjustments can be triggered in a *proactive* fashion, based on people's expectancies or anticipation of future events. Early support for or a role of subjective expectancy in cognitive control was gathered by manipulating expectancies *implicitly*, for instance by varying the probability of incongruent versus congruent trials (Logan & Zbrodoff, 1979; 1982; Tzelgov, Henik, & Berger, 1992). These adjustments to frequent conflict, reflected in a reduced congruency effect for mostly incongruent blocks, were interpreted in terms of deliberate adjustments in response strategy based on probabilistic expectancies exploited by participants. Importantly, such strategic adaptations to frequent conflicting events (or the absence thereof) are only observed when the irrelevant dimension that elicited the conflict is consciously perceived (Merikle & Joordens, 1997; Merikle, Joorden, & Stolz, 1995). This corroborates the voluntary aspect of such proactive adjustments. However, the debate on the exact mechanism underlying proportion congruency effects is still ongoing, but a thorough discussion of this issue falls beyond the scope of this introduction (see Abrahamse, Duthoo, Notebaert, & Risko, 2013; Bugg & Crump, 2012, and Schmidt, 2013, for recent overviews).

More commonly, expectancy-based anticipatory control has been probed more *explicitly*, by means of informative cues alerting the participants which control setting is most appropriate for the upcoming target (Aarts, Roelofs, & van Turennout, 2008; Aarts & Roelofs, 2011; Correa, Rao, & Nobre, 2009; Gratton et al., 1992; Logan & Zbrodoff, 1982; Strack, Kaufmann, Kehrer, Brandt, & Stürmer, 2013). Importantly, these studies have generally suggested that these cues elicited control adjustments independent of response conflict. Whereas CMT posits that control is low following congruent trials, leading to slow reactions on the next incongruent trial, proactive control accounts postulate that congruent-predicting cues can also evoke control adjustments, leading to faster reactions on the next congruent trial (e.g., by allowing the irrelevant word dimension to contribute more strongly to response selection).

Moreover, a proactive account argues that participants can also strategically exploit the relation between the relevant and irrelevant stimulus dimension in anticipation of an incongruent trial. When only two stimuli are used in a Stroop task, such strategic shortcuts can lead participants to respond to incongruent trials by choosing the response associated with the colour opposite of that indicated by the presented word (see also Wühr & Kunde, 2008, for evidence of strategic attention shifting in a Simon conflict task). In a context of a high proportion of incongruent trials, such strategic shortcuts may give rise to a reversed congruency effect (Logan & Zbrodoff, 1982), with shorter reactions to incongruent compared to congruent trials. Such findings are hard to reconcile with a conflict-driven account, where performance on incongruent colours can, at best, be equal to that on congruent trials. The debate is still open to what extent preparatory control is restricted to such attention switch strategy, or can as well exert its influence by gradually amplifying or suppressing the relevant and irrelevant stimulus dimensions – so-called attentional gating. Whereas this has been confirmed in a visual search paradigm (Müller, Reimann, & Krummenacher, 2003), Wühr and Kunde (2008) found only evidence for strategic attention switching, but not gating, in a variant of the Simon conflict task.

TASK SWITCHING

In the task switching domain, the robust finding of a switch cost (the difference in reaction time between task repetitions and task shifts) suggests that conflict or interference from previous task-sets has to be resolved for successful switching, emphasizing the need for cognitive control. When participants are provided with an advance instruction cue and ample preparation time, task switch costs are strongly reduced. This finding was taken to suggest that participants can prepare for an upcoming task, and thus can engage in cognitive control proactively (De Jong, 2000; Lien, Ruthruff, Remington, & Johnston, 2005; Meiran & Chorev, 2005; Rogers & Monsell, 1995). Indeed, more than in congruency tasks, task switching studies have focused on this anticipatory control component, sometimes referred to as task-set reconfiguration (De Jong, 2000; Meiran, Chorev, & Sapir, 2000), which enables proactive switching to the other task in response of a cue (Monsell, 2003). This task-set reconfiguration can entail both inhibiting the previous task-set and activating the new task-set. There is not only evidence for preparatory reductions in switch costs (e.g., Koch, 2003); advance preparation can also lead to reaction time benefits on task repetitions (Dreisbach, Haider, & Kluwe, 2002).

Notwithstanding the emphasis on this anticipatory control component, also reactive influences of the previous trial (e.g., task-set inertia; Allport, Styles, & Hsieh, 1994) or stimulus-driven, bottom-up associative effects (e.g., binding between stimuli and task-sets, Waszak et al., 2003) have been considered. In this light, it has been discussed whether the difference in RT between task repetitions and switches effectively represents the cost of reconfiguring the cognitive system in order to switch tasks, or rather the benefit of repeatedly executing the same task. Whereas the first view stresses an endogenous, proactive control component, the second view considers the slowing on task switches as a more automatic, exogenous carry-over effect from the previous task (Allport et al., 1994). Moreover, the issue has been raised that part of the cueing effects in task switching may be due to cue-encoding benefits rather than advance preparation (Logan & Bundesen, 2003; but see Brass & von Cramon, 2004; De Baene & Brass, 2011; Jost, De Baene, Koch, & Brass, 2013; Monsell & Mizon, 2006).

Apart from these considerations, the robust finding of a residual switch cost with ample preparation time has led to the suggestion that even if advance preparation is a viable explanation for task switch costs, it appears to be restricted in nature. Here too, unresolved reactive interference from the previous task-set or interference from previous stimulus-task bindings has been proposed to explain the residual switch cost (Allport et al., 1994; Waszak et al., 2003). This was countered by the proposal that complete preparation is possible, yet that this effortful preparation sometimes occurs before stimulus onset, and sometimes also after stimulus onset. In other words, the residual switch cost reflects sporadic failures to engage (De Jong, 2000). According to De Jong, participants try to find an optimal balance of advance preparation that allows for sufficient task performance, since task-set reconfiguration is an effortful process. Further support that complete advance preparation is possible was given by Verbruggen, Liefooghe, Vandierendonck, & Demanet (2007), who showed that removing the cue during the preparation interval encouraged participants to fully prepare in advance, thereby successfully eliminating the residual task switch cost. Dreisbach & Haider (2006) further showed that preparatory control processes can be dynamically adjusted to the expected task demands, by using either local probabilistic cues or global probability information about the chances of a task switch. In sum, task switching studies suggest that anticipatory control can effectively configure the cognitive system for future events.

THE ROLE OF EXPECTANCIES

As can be derived from the studies reviewed above, most of the evidence in favour of proactive control stems from explicit cueing studies, which suggest that people are able to prepare for an upcoming target, conflict or task switch. In the absence of such explicit cues, theoretical alternatives have been suggested that do not rely on anticipatory, expectancy-driven control adjustments to ensure adaptive, goal-directed behaviour. To what extent proactive control adjustments are called upon when there are no cues to predict the forthcoming events, remains to be explored in more depth. This question was central to all of the empirical chapters enclosed in this thesis.

In the present dissertation, ‘proactive control’ was thus assessed by manipulating participants’ expectancies about upcoming stimulus events and investigating the effects of these manipulations on well-known markers of cognitive control, including the congruency sequence effect and the task-switch cost. Apart from being manipulated implicitly in some of the chapters, expectancies were also measured explicitly in the majority of the chapters. This further allowed looking for patterns or biases in expectancies that can otherwise only be inferred indirectly. Applied to congruency tasks, expectancy-induced control adjustments were contrasted with conflict-induced adjustments. Applied to task switching, the effect of explicit expectancies on task performance was compared to previous studies with the explicit cueing paradigm.

In sum, proactive and reactive control were contrasted by probing the role of expectancies. How this approach differs from other theoretical distinctions between reactive and proactive control will be touched upon in the General Discussion.

RESEARCH GOALS AND OVERVIEW OF THE THESIS

The aim of the present thesis was to further investigate the relative contributions of proactive and reactive control in aligning our behaviour with external goals or task demands. An important step in this pursuit was to pinpoint the role of expectancies in cognitive control. To this end, expectancies were both manipulated implicitly and measured explicitly, as to evaluate their impact on well-known markers of cognitive control. More specifically, the extent to which expectancy-guided attentional adjustments contribute to congruency sequence effects and task switch costs was put to the test. Expectancies themselves were also considered as an extra measure of cognitive control, and contextual influences on expectancies about future events were taken into account. *Chapters 3*, *4* and *5* investigated potential biases in participants' predictions, and the impact of this on performance. Apart from knowing what future event is likely to happen, expectancies about when these events are likely to happen might also be crucial to evoke anticipatory control. *Chapter 6* was dedicated to the role of temporal predictability and motivational influences on proactive control adjustments. Finally, this dissertation also aimed to further our understanding of some of the underlying neural mechanisms involved in proactive and reactive control, by applying the event-related potential technique (*Chapter 5*). Apart from this Introduction (*Chapter 1*) and a General Discussion (*Chapter 7*), there are five empirical chapters bundled in this dissertation. Each of these chapters was written as an individual paper. In the following, these empirical studies are briefly outlined.

In *Chapter 2,* two behavioural experiments are reported that aimed to critically contrast three different explanations for the congruency sequence effect (CSE). In order to control for confounding effects of feature integration and associative learning, we construed a vocal Stroop task with eight different colours, so that no stimulus feature was repeated over consecutive trials. As to adjudicate between an interpretation of the CSE in terms of conflict monitoring and one in terms of repetition expectancy, participants' expectancies for the congruency level to repeat or alternate across consecutive trials were implicitly manipulated. To this end, the probability for congruency level repetitions was either raised or decreased, and the influence of this manipulation was probed in a test block, for which the probability of a congruency level repetition was reset to 50%. If repetition expectancy crucially drives sequential effects, a transfer of the induced expectancies to performance in the test blocks was predicted.

In *Chapter 3,* the role of expectancies in cognitive control was put to the test more directly. Participants were asked to explicitly indicate their prediction for the congruency level of the upcoming trial. This allowed a more direct test of the assumption made by Gratton et al. (1992) that participants in a conflict task display the counterintuitive tendency to expect repeating stimulus conditions. Whereas a proactive account predicts a repetition bias and an influence of these expectancies on subsequent Stroop performance, a reactive account does not. To further probe the influence of episodic memory effects and feature integration, we investigated the effect of predictions on performance in a 2-colour and 4-colour Stroop task, as well as in the 8-colour Stroop task employed in the previous chapter.

In parallel to the experiments of Chapter 3, an identical procedure was applied on a task-switch paradigm combining magnitude and parity judgments in *Chapter 4*. Here too, participants' expectancies about the upcoming task were explicitly measured. Irrespective of participants' task predictions, the colour of the target indicated which task participants were supposed to perform. The switch rate was varied in three between-subjects conditions (30, 50, & 70%). The aim of the study was to relate the finding of decreased switch costs with increasing switch rate (Mayr, 2006; Monsell & Mizon, 2006) to variations in participants' expectancy for a task alternation. It was hypothesized that following a task alternation prediction, the cost of task switch would be reduced (or the benefit for task repetitions reduced). This would lend further credit to the role of expectancy in the context-sensitive adjusting of task switching performance.

In *Chapter 5*, the effect of explicit congruency level predictions on Stroop conflict resolution was further investigated using EEG. The interplay between proactive and reactive effects on Stroop task performance was verified by looking for prediction-driven differences in advance preparation during the pre-stimulus interval (reflected in the contingent negative variation (CNV) component) as well as by disentangling the impact of predictions and previous conflict on markers of cognitive control in the Stroop task (e.g., the N450 and conflict slow potential).

Next, *Chapter 6* tested the hypothesis that proactive cognitive control not only benefits from knowing *what* to expect (as in the previous chapters), but will also be more optimally recruited when one knows *when* the event is likely to occur. In a recent study, Egner, Ely, & Grinband (2010) varied the response-to-stimulus (RSI) interval to show that congruency effects decline over time, which was interpreted as evidence for rapidly decaying, reactive adjustments in cognitive control. In this chapter, an RSI proportion manipulation was applied to verify whether increasing the probability of stimulus appearance at the longer RSI promoted the chance (and potentially also the will) to engage in a proactive control strategy.

Box 2 – Event-related Potentials

In Chapter 5, we recorded the electroencephalogram (EEG). EEG visualizes the electrical activity on the scalp while information travels through the brain. Its main advantage is the high temporal resolution, which allows dissociating the flow of information time-locked to events (stimuli or responses) that often only last for several milliseconds. Electrical waves are averaged over multiple occurrences of the same event for each psychological condition of interest, creating event-related potentials (ERPs), as illustrated below.

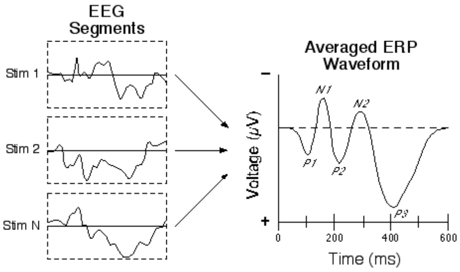

Figure 1. From EEG to ERP. Image taken from: https://uwaterloo.ca/event-related-potential-lab

The resulting ERPs reflect the neural manifestation of the information processing associated with the stimulus events. The amplitude and latency of the averaged voltage deflections are then quantified and compared over the different experimental conditions. For example, in a traditional Stroop task, average ERP waveforms for low-conflict congruent (‘BLUE’ in blue) and high-conflict incongruent (‘BLUE’ in yellow) conditions are created. The negative peak around 450 milliseconds has been consistently found to be more pronounced for incongruent trials compared to congruent trials, supposedly reflecting the detection of conflict (Larson et al., 2009). The scalp map shows that this difference is most pronounced along fronto-central electrodes.

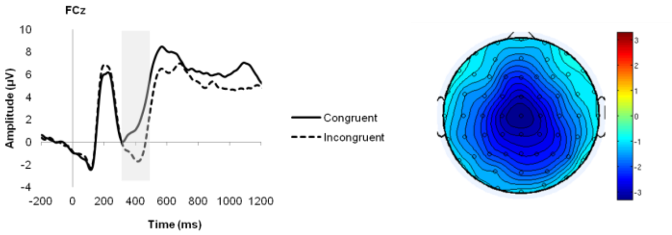

Figure 2: Grand Average ERP waveforms for congruent and incongruent trials at electrode FCZ

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CHAPTER 2

THE CONGRUENCY SEQUENCE EFFECT: IT IS NOT WHAT YOU EXPECT[1]

In two experiments, a vocal Stroop task with eight different colours was employed in order to put two core assumptions of the original interpretation of the congruency sequence effect (CSE; Gratton, Coles, & Donchin, 1992) to the test. We verified whether control processes can elicit this sequential modulation when episodic memory effects are controlled for, and to what extent proactive adjustments driven by participants' expectancies for congruency level repetitions contribute to the CSE. To this end, we presented Stroop stimuli without feature repetitions and investigated whether the induced expectancy manipulation of raising the amount of either congruency level repetitions or alternations in a training phase transferred to an unmanipulated test phase. Over the two experiments, a sequential modulation of the Stroop effect was found in the absence of stimulus feature repetitions, strongly confirming a share for attentional control processes in bringing about the CSE. In the condition where congruency level repetitions were raised, a strong CSE was found. When congruency level alternations outnumbered repetitions, the CSE disappeared completely. However, this difference seemed mainly due to cumulative effects of local, dynamic trial-to-trial control adjustments rather than expectancy-induced attentional shifting. Once the transition probability changed back to 50% in the test phase of each experiment, a similar CSE was found in both conditions. Taken together, these results are best explained in terms of dynamic reactive control.

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[1] This chapter is based on: Duthoo, W., & Notebaert, W. (2012). Conflict adaptation: It is not what you expect. *Quarterly Journal of Experimental Psychology, 65*, 1993-2007.

INTRODUCTION

Adaptively dealing with situations in which two incompatible action tendencies compete for execution is one of the central challenges of human cognition. When driving carefully on the freeway, for example, the cars speeding by might urge you to push the gas pedal down further, whereas the speedometer might instruct you otherwise. In the light of how the cognitive system solves these kinds of response conflict, existing theoretical accounts can be discerned on the basis of the relative emphasis they place on two different control processes (see e.g., Wühr & Kunde, 2008). *Reactive* control processes, on the one hand, ensure that the cognitive system adjusts information-processing after the occurrence of an action conflict. *Proactive* control processes, on the contrary, aim to adaptively optimize the system in anticipation of an expected conflict. One can indeed slow down in reaction to the incompatibility between the speedometer and the surrounding cars or, alternatively, decide to concentrate more heavily on the speedometer in advance, in order to avoid a possible action conflict.

When investigated within a laboratory setting, these response conflicts are mostly experimentally induced by means of a conflict paradigm, like the Simon, Stroop or flanker task. To shed some light on how the human cognitive system adapts to these conflicts, the congruency sequence effect (CSE), first reported in the study of Gratton, Coles, and Donchin (1992) and hence later on termed the *Gratton effect*, quickly became central to the cognitive control research (for a review, see Egner, 2007). Gratton and colleagues applied a standard flanker task, in which reactions to the central target of compatibly flanked trials (e.g., <<<) are generally faster and less error-prone than reactions to trials containing incompatible flankers (e.g., <><). Beyond this general congruency effect, the authors reported an interaction between previous and current trial congruency: the congruency effect was found to be smaller following an incongruent stimulus than following a congruent one. They theorized that these sequential differences in the size of the congruency effect reflected strategic cognitive control adaptations brought about by the optimization of attentional strategies and that this optimization process relied on participants' expectancies regarding the nature of the upcoming trial. This Gratton effect, visualized in Figure 1A, has been replicated for conflict tasks other than the flanker paradigm, including the Simon (Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002) and the Stroop (Kerns et al., 2004) task.

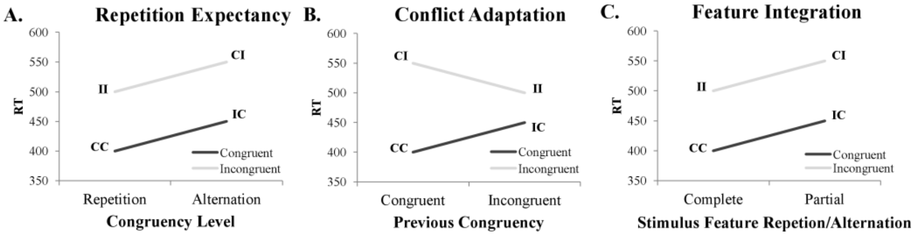


Figure 1: Three explanations for the congruency sequence effect. For the repetition expectancy account (A), reaction times for congruent and incongruent trials are plotted in function of a congruency level repetition or alternation. The conflict adaptation account (B) takes the congruency level of the previous trial into account. For the feature integration account (C), the amount of stimulus feature overlap in consecutive trials is highlighted. RT = reaction time. C = congruent. I = incongruent.

One of the more crucial hypotheses concerning this expectancy account is the underlying assumption that participants tend to expect that a particular stimulus condition on a given trial will be repeated on the next one, as evidenced by Remington (1969). So even when congruent (C) and incongruent (I) trials are objectively equally likely to be presented, subjects still predict that the trial following a congruent one will be another congruent trial, whereas incongruent trials are expected to be followed by incongruent ones. Applied to the flanker task, this repetition expectancy suggests that participants adaptively shift their attention to a focused processing strategy when anticipating an incongruent stimulus, as to weaken the impact of the misleading flanking stimuli hindering performance (Gratton et al., 1992). In anticipation of a congruent trial, Gratton and colleagues suggested that participants change to a more parallel attentional focus, so that facilitation from congruent flanker information on response selection is increased. This adaptive regulation of attentional strategies leads to relatively faster reaction times on CC and II transitions compared to IC and CI sequences, since expectations are confirmed in the former, but violated in the latter. In sum, this *repetition expectancy account* (Egner, 2007) predicts faster reaction times for congruency level repetitions than for congruency level alternations, as depicted in the illustration of the Gratton effect in Figure 1A. Importantly, this expectancy-driven account clearly emphasizes proactive control processes.

The theoretical considerations of Gratton and colleagues (1992), however, quickly faded to the background of the theoretical discussion with the formulation of the highly influential conflict monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001). These authors agreed that the CSE provided a direct window onto attentional online adaptations in cognitive control, but the conflict monitoring loop they proposed emphasized the experienced conflict rather than participants' expectancies and thus shifted the theoretical emphasis towards reactive control processes. According to this account, the need for cognitive control is signalled by an evaluative mechanism (situated in the anterior cingulate cortex, ACC) constantly monitoring for internal processing 'conflict'. The model conceptualized this 'conflict' as the simultaneous activation of mutually incompatible neural representations. Once conflict is detected, a signal is sent to a regulative control component (thought to be implemented by the lateral prefrontal cortex) that in turn triggers strategic top-down adjustments in processing, thus lowering the impact of subsequent conflict. The model implements this enhancement in cognitive control by adjusting attentional weights of task-relevant and task-irrelevant stimulus dimensions, so that information processing becomes more in line with the current task demands.

Applied to performance in a congruency task, the conflict monitoring theory states that cognitive control enhances the processing of task relevant stimulus information after high-conflict incongruent trials, *irrespective* of participants' expectancy for the upcoming trial. This transient control up-regulation leads to a speed-up on an upcoming incongruent trial (II compared to CI trial transitions) by reducing the interference from the irrelevant stimulus dimension or to a slowdown on the next congruent trial (IC compared to CC trial transitions) by reducing the facilitation of congruent irrelevant stimulus information. In contrast, low conflict congruent trials result in a down-regulation, so that control is weaker on subsequent trials and a stronger interference effect is predicted. This interpretation of the congruency sequence effect is visualized in Figure 1B. By emphasizing reactive, post-conflict adaptation processes, the *conflict monitoring theory* introduced a shift away from the proactive control view proposed by Gratton and colleagues (1992).

In recent theorizing, proactive and reactive control processes are treated more and more as complementary rather than mutually exclusive. De Pisapia and Braver (2006), for example, hypothesized that transient, trial-by-trial reactive adaptations occur simultaneously with a superimposed proactive, probability-exploiting control strategy. In their computational model, reactive control is conceptualized as a short-lived, transient activation of the prefrontal cortex (PFC) triggered by conflict detection in the anterior cingulate cortex (ACC). Proactive control, on the other hand, is implemented as a sustained maintenance of the task-set within a different PFC module that is triggered by a separate ACC unit sensitive to conflict over a longer time-scale. Their model successfully fitted the variations in reaction time as well as the patterns of PFC and ACC activity found within humans performing the Stroop task. It remains unclear, however, whether probabilities or expectancies can also proactively regulate attentional processing on a trial-by-trial basis, as no study has yet attempted to disentangle reactive and proactive trial-to-trial control processes within a conflict task.

Still, the repetition expectancy account as well as the conflict adaptation hypothesis has been challenged by alternative explanations in terms of episodic memory effects of stimulus-response associations, excluding the role of higher-level attentional control mechanisms completely. On the basis of Hommel’s *feature integration account* (1998), it has been argued that the reaction time pattern of the CSE is due to the sequence of specific stimulus features that may or may not (partially) overlap (Hommel, Proctor, & Vu, 2004; see also Notebaert, Soetens, & Melis, 2001). According to this theory, features of stimuli and responses that co-occur in time get temporarily integrated into a common episodic memory representation. Crucially, activation of any of those features on the subsequent trial automatically co-activates the remaining features. Therefore, complete stimulus-response feature repetitions (e.g., GREEN in red ink followed by GREEN in red ink in a traditional Stroop colour naming task), as well as complete alternations (e.g., GREEN in red ink followed by BLUE in yellow ink) lead to relatively faster responses because no previous feature binding needs to be overcome. Partial stimulus feature repetitions (e.g., GREEN in red ink followed by GREEN in blue ink), on the other hand, give rise to relatively slower reactions, since previous binding of features has to be undone. As shown in Figure 1C, the interaction between previous and current congruency depicted in Figure 1B can be re-interpreted in terms of complete and partial stimulus feature repetitions or alternations.

Following a similar reasoning, Mayr, Awh, and Laurey (2003) pointed out that in an interference task employing only two stimulus values, sequences involving complete stimulus (and response) repetitions may lead to repetition priming effects that mimic the pattern of a typical CSE. When the authors excluded direct repetitions from the analyses, no sign of conflict adaptation was found. Nevertheless, studies that aimed at explicitly controlling for repetitions of stimulus and response features as well as for transitions involving negative priming, either by experimental (Akçay & Hazeltine, 2007; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006) or statistical control (Notebaert & Verguts, 2007) still reported evidence for a CSE, suggesting that sequential modulations are not entirely due to stimulus and/or response repetition effects. However, as these studies all rely on the analysis of the highly selective data set that remains after exclusion of all trial transitions in which features repeat, a more stringent and elegant test is needed to better evaluate the contribution of cognitive control processes in bringing about the CSE.

The aim of this study was to critically evaluate the relative explanatory value of the repetition expectancy and conflict adaptation account within the same experiment, while at the same time controlling for the feature integration account. In this way, two core assumptions of the original interpretation of the CSE (Gratton et al., 1992) are put to the test. Firstly, and most fiercely debated, does this effect reflect a genuine attentional control mechanism, rather than more basic episodic memory processes (i.e., the binding and unbinding of stimulus features)? Secondly, and practically uninvestigated, to what extent do *proactive* adjustments driven by participants' expectancy for the congruency level to repeat contribute to conflict adaptation?

Therefore, a vocal Stroop task with eight different colour words was employed. In order to better control for potentially confounding episodic memory effects, the experiments were set up so that all possible stimulus feature repetitions were excluded beforehand, instead of excluded post hoc. If a CSE would still emerge within the present design, an explanation in terms of attentional control adjustments rather than episodic memory processes seems more apt. Since all transitions were programmed to be complete stimulus feature alternations, findings of a CSE in the two experiments would evidence a contribution of cognitive control processes more convincingly and elegantly than previous attempts (i.e., post hoc exclusion of certain trial transitions or stepwise multiple regression approaches).

In order to further clarify the role of participants' expectancies in bringing about the CSE, we set up an experimental design with two conditions differing only in the probability of congruency level repetitions during a training phase, while keeping the overall proportion of congruent and incongruent trials equal. In the *repetition condition* we raised the probability of repeating stimuli of the same congruency level, so that after a congruent trial there was a higher chance to encounter another congruent trial, whereas incongruent trials were mostly followed by incongruent trials (the congruency level repeated in on average 70% of the trial transitions).

The *alternation condition*, on the other hand, raised the probability of alternating the congruency level, leading to alternations in on average 70% of the transitions.

However, it is hard to isolate a potential effect of repetition expectancy within these manipulated trial sequences, as the manipulation might also change reactive control processes (e.g., Durston et al., 2003). To better evaluate the effect of the induced expectancies, we introduced a test phase, during which the transition manipulation was left out and standard experimental conditions with a 50% chance of a congruency level repetition or alternation were created. If differential expectancies are sufficiently induced, we then can look for a transfer effect from the manipulated training phase to the unmanipulated test phase. In the first experiment, the last two out of six experimental blocks formed this test phase, whereas during the second experiment these trials were integrated at the halfway point of each of the five experimental blocks.

Over the two experiments, we investigated whether the manipulation of transitional probabilities led to behavioural differences (variations in the size of the CSE between the two conditions), both in the manipulated stimulus lists and in the trials of the test phase. If the CSE is driven by expectancy-induced attentional control strategies, we predict to find a stronger CSE in the repetition condition compared to the alternation condition in the training phase, and a transfer of this difference to the test phase. Alternatively, if participants are more sensitive to the local previous trial congruency level than to the global congruency level repetition probabilities, we predict to find no difference between the two conditions in the test phase, nor in a specific subset of trial transitions with an identical conflict history in the manipulated phase. The former would be evidence in favour of a share of proactive control processes in bringing about the CSE, whereas the latter would strongly confirm that reactive control processes are more dominant in congruency task performance.

EXPERIMENT 1

In the first experiment, we set out to investigate if the manipulation of participants' expectancy for the congruency level to repeat leads to differences in the size of the CSE, and if these differences persist during a test phase when the expectation manipulation was left out. The first four of six experimental blocks served as the training phase, in which the transition manipulation was present, whereas the last two blocks formed a test phase, where the amount of congruency level repetitions was identical between the two conditions. In the training phase of the *repetition condition*, the amount of congruency level repetitions was raised, whereas for the *alternation condition* a higher amount of congruency level alternations was presented. We predict the CSE to be larger in the repetition condition than in the alternation condition. Investigation of a potential transfer of this difference between the two conditions to the test phase can critically differentiate between the conflict adaptation and repetition expectancy account.

METHOD

Participants. A group of 32 Ghent University students signed up to participate in the experiment that lasted for approximately one hour. They received either course credits or a monetary payment in return. Prior to the testing, participants provided written informed consent.

Stimuli and Apparatus. The stimuli were displayed on a 17-inch monitor of a Pentium processor using T-scope software (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 2006), with a viewing distance of approximately 50 centimetres. Each Stroop stimulus consisted of one out of eight possible colour words ('RED', 'GREEN', etc.) printed out centrally on a black background in one of the eight possible colours (red, green, blue, yellow, pink, brown, purple or grey) and was presented in Courier font, size 20. Participants had to react by saying out loud the colour of the words. The responses were detected by means of a Sennheiser MD 421-U-4 microphone placed slightly below the participants' mouth, triggering in turn an adapted voice key optimized for reaction time experiments (i.e., a noise elimination voice key, see Duyck et al., 2008). The experiment was run in a regular, dimly lit, quiet office room.

Design and Procedure. Participants were randomly assigned to one of the two experimental conditions, differing only in the probability of a congruency repetition in the course of the first four blocks (referred to as the training phase). In the *repetition condition*, the program raised the probability of repeating stimuli of the same congruency, so that after a congruent trial (‘GREEN’ in green ink) there was more chance to encounter another congruent trial, whereas incongruent trials (‘GREEN’ in red ink) were mostly followed by incongruent trials (the congruency level repeated in on average 70% of the experimental transitions). In *the alternation condition*, on the other hand, we raised the probability of alternating the congruency level, leading to alternations in on average 70% of the transitions. In both conditions, the overall proportion of congruent and incongruent trials was equal (i.e., 50%). During the last two blocks of both experimental conditions (referred to as the test phase), the sequence manipulation was left out, creating the standard random succession of trials with the percentages of congruency repetitions and alternations being equal. The experiment thus consisted of six blocks of 146 trials each, adding up to a total of 876 trials. Colour word and ink colour were randomly filled in by the program on a trial-by-trial basis, with the restriction of neither complete stimulus repetitions nor relevant, irrelevant, relevant-to-irrelevant or irrelevant-to-relevant feature repetitions occurring, as to eliminate the effects of stimulus feature repetitions hindering the interpretation in terms of conflict adaptation (as discussed in Mayr et al., 2003).

The participants’ task was to verbally identify the colour in which the words appeared on the screen as fast as possible, while ignoring the irrelevant word meaning. Speed and accuracy were equally stressed. Verbal instructions were provided by the experimenter. Before the actual experiment, participants received some practice with the voice key and the task during 24 practice trials. Each experimental trial started with the presentation of a fixation dot for 500 ms, after which the stimulus word appeared on screen until a response was registered by the microphone, with the maximal reaction time restricted to 2000 ms. The moment the voice key was triggered, the stimulus word shortly tilted 20° to the right for 300 ms before the screen turned black and the experimenter coded the actual response given by the participant. When the voice key was triggered too early (caused by a noise other than the participant's voice) or too late (because of the participant hesitating, hissing or raising his or her voice during the response), the experimenter coded the trial as a false alarm. After coding, another 500 ms passed before the next trial begun. No error feedback was provided. In between two blocks, the participants took a short, self-paced break.

RESULTS

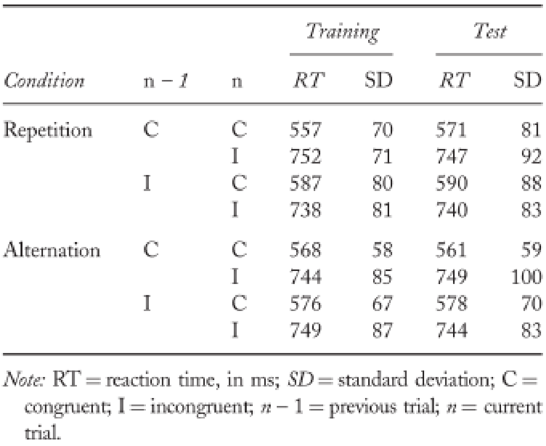
Before conducting statistical analyses, the data were subjected to a trimming procedure. First of all, the misses and false alarms caused by voice key malfunctioning were eliminated, amounting to a total exclusion of 6.7% of the data. Errors were also excluded from the analyses (1.9%). However, the distinction between these performance errors and errors due to erroneous voice key registration is rather blurry (i.e., when participants correct their responses). Therefore, and also because of the overall small amount of errors, we decided not to include error analyses in the studies reported here. Then, the first trial of each block and RT outliers (± 2.5 *SD*, calculated separately per condition, subject and congruency level) were removed (adding up to 3% of the remaining data). Since we focus on sequential analyses, the responses immediately following an error trial or non-response were eliminated as well (another 6.2%). Even though this removal procedure led to the exclusion of relatively more incongruent trials compared to congruent ones (18% and 15%, respectively), the data loss was of equal size in both conditions ($F(1, 30) < 1$, *ns*). Taken together, the data analysis was thus carried out on the remaining 83.3% of the trials.

A mixed-design analysis of variance (ANOVA) with the within-subject factors Experimental Phase (two levels: training and test), Previous Congruency (two levels: congruent and incongruent) and Current Congruency (two levels: congruent and incongruent) and the between-subject factor Experimental Condition (two levels: repetition and alternation) was carried out. Firstly, a Stroop effect of 159 ms was found, $F(1, 30) = 374.4$, $p < 0.001$, that did not differ between the two experimental conditions, $F(1, 30) < 1$, *ns*. This congruency effect interacted significantly with Previous Congruency, $F(1, 30) = 33.73$, $p < 0.001$, indicating an overall CSE. Importantly, the four-way interaction between Experimental Phase, Current Congruency, Previous Congruency and Experimental Condition reached significance, $F(1, 30) = 5.81$, $p < 0.05$. This four-way interaction stemmed from a difference between the repetition and the alternation condition, but only within the first four experimental blocks. Mean reaction times and standard deviations for the different conditions are summarized in Table 1.

During those first four blocks, a significant interaction between Previous and Current Congruency emerged, $F(1, 30) = 23.46$, $p < 0.001$. Most important, the significant three-way interaction with Experimental Condition indicated that this CSE was much larger in the repetition condition compared to the alternation condition, $F(1, 30) = 17.65$, $p < 0.001$. The Stroop congruency effect in the repetition condition was strongly reduced after incongruent compared to congruent predecessors: a reduction from 195 ms to 151 ms, and thus a CSE of 44 ms, $t(15) = 5.41$, $p < 0.001$. In the first four blocks of the alternation condition there was no sign of a CSE: the Stroop effect following congruent and incongruent predecessors was not significantly different: 176 ms and 173 ms, respectively, $t(15) < 1$, *ns*.

For the last two blocks constituting the test phase, again a significant CSE was found, $F(1, 30) = 14.7$, $p < 0.001$, but contrary to the findings of the training phase, this effect did not vary significantly between the two experimental conditions, $F(1, 30) < 1$, *ns*. This indicates the presence of a comparable CSE for both conditions. For the repetition condition the Stroop effect was reduced from 176 ms after congruent trials to 150 ms after incongruent trials, $t(15) = 3.82$, $p < 0.01$. For the alternation condition, the reduction from 188 ms to 166 ms was also significant, $t(15) = 2.11$, $p = 0.05$.

Table 1: Mean reaction times and standard deviations as a function of the congruency level of the previous and current trials for the training and test phases of the repetition and alternation conditions in Experiment 1.



			Training		*Test*	
Condition	n − *1*	n	*RT*	SD	*RT*	SD
Repetition	C	C	557	70	571	81
		I	752	71	747	92
	I	C	587	80	590	88
		I	738	81	740	83
Alternation	C	C	568	58	561	59
		I	744	85	749	100
	I	C	576	67	578	70
		I	749	87	744	83

Note: RT = reaction time, in ms; *SD* = standard deviation; C = congruent; I = incongruent; *n* − 1 = previous trial; *n* = current trial.

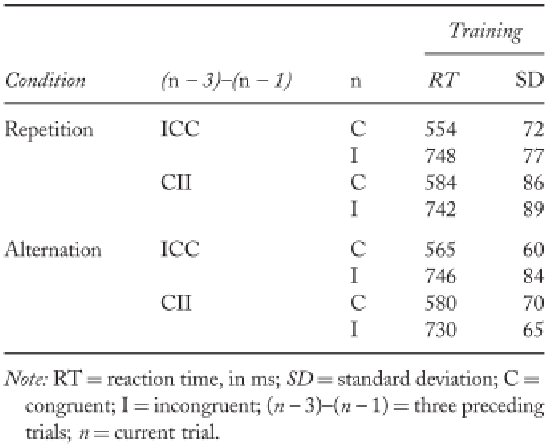
DISCUSSION

Importantly, the finding of a significant CSE in the absence of stimulus feature repetitions clearly supports an explanation of this effect in terms of attentional control. Secondly, the frequency manipulation did have an impact on the size of the CSE, appearing only in the repetition condition and not in the alternation condition. However, this difference in the CSE is not unequivocally attributable to differential expectancies about the upcoming congruency level in the two conditions, as previous research (e.g., Durston et al., 2003) has shown that long repeated sequences of congruent or incongruent trials evoke cumulative effects on reaction times. Consequently, the observed difference in the CSE might equally well be due to reactive, local trial-to-trial changes compatible with the conflict monitoring theory (Botvinick et al., 2001).

In order to verify whether the overall congruency level repetition probability had an impact on the CSE in trial sequences with an identical conflict history, we ran another mixed-design ANOVA on trial transitions involving a local congruency level repetition from trial *n*-2 to *n*-1. As this local repetition will mostly be preceded by a much longer run of repetitions in the repetition condition, we only included the transitions that involved a congruency alternation at trial *n*-3. In other words, we restricted the analysis of the Gratton effect to the following specific set of transitions: ICCC; ICCI, CIIC and CIII. Any remaining difference in the CSE between the two conditions for these identical transitions would then point to an effect of congruency level expectancies on attentional control. However, even though a significant interaction between the factors Previous Congruency and Current Congruency still emerged, $F(1, 30) = 9.35$, $p < 0.01$, the three-way interaction with Experimental Condition did no longer appear, $F(1, 30) < 1$, *ns*. The mean reaction times and standard deviations for the different conditions are summarized in Table 2. Even though carried out on a limited amount of trials, this extra analysis suggests that reactive processes sensitive to the local conflict history rather than proactive processes dependent on global conflict repetition probabilities have driven the difference in the CSE between the conditions in the training phase. Moreover, the lack of a transfer effect of the induced expectancies from the training to the test phase pointed in a similar direction.

However, as we assume that effects of expectancies become more pronounced when more preparation time is provided (see also Egner, Ely, & Grinband, 2010, for a similar reasoning), we tried to encourage participants to build up congruency level expectancies more strongly by stretching the presentation of the fixation dot to 2000 ms in Experiment 2. Moreover, due to the late timing of the test phase (i.e., the last two blocks) in Experiment 1, effects of practice, fatigue or boredom might have obscured the transfer effect. Therefore, training and test phases alternated earlier and more frequently in Experiment 2.

Table 2: Mean reaction times and standard deviations as a function of conflict history on the previous three trials and the congruency level of the current trial for the training phases of the repetition and alternation conditions in Experiment 1.



			Training	
Condition	*(n − 3)–(n − 1)*	n	*RT*	SD
Repetition	ICC	C	554	72
		I	748	77
	CII	C	584	86
		I	742	89
Alternation	ICC	C	565	60
		I	746	84
	CII	C	580	70
		I	730	65

Note: RT = reaction time, in ms; *SD* = standard deviation; C = congruent; I = incongruent; (*n* − 3)–(*n* − 1) = three preceding trials; *n* = current trial.

EXPERIMENT 2

In Experiment 2, we further optimized the experimental design of an otherwise identical vocal Stroop task, by mixing in a separate test phase during each of the five experimental blocks. At the halfway point of each block, the transitional probabilities changed to 50% for 36 trials, after which the sequential manipulation of the training phase was reintroduced until the break. In line with the findings of Experiment 1, we predicted an overall greater CSE in the repetition condition. Because the two phases smoothly ran over into each other and expectancies were allowed to grow stronger during the prolonged fixation interval, we also predicted a transfer effect of the transitional manipulation.

METHOD

The design and procedure of Experiment 2, as well as the stimuli and apparatus used, closely resembled those of Experiment 1. In what follows, only the specific modifications made in procedure and design are described.

Participants. A group of 30 Ghent University students signed up to participate in the experiment, lasting approximately one hour. They received either course credits or a monetary payment in return. Prior to the testing, participants provided written informed consent.

Design and Procedure. Again, participants were randomly assigned to one of the two experimental conditions (15 in the *repetition* condition, 15 in the *alternation* condition). In each of the training phases, the congruency level either alternated or repeated with a 70% probability. For each of the test phases, the standard random succession of trials (i.e., 50%) was applied. Colour word and ink colour were again randomly filled in by the program on a trial-by-trial basis. Each block started with a training phase of 74 trials with either more repetitions or alternations. Then, the test phase followed, containing 36 trials. For the last 38 trials, the transitions changed again from 50 to 70% of either congruency level repetitions or alternations. For the statistical analyses, these last 38 trials were added to the training phase. The experiment thus consisted of five blocks of 148 trials each, adding up to a total of 740 trials.

Each experimental trial started with the presentation of a fixation dot for 2000 ms. Then, the screen turned black for 500 ms, after which the stimulus word appeared on screen until a response was registered by the microphone, with the maximal reaction time restricted to 2000 ms. The moment the voice key was triggered, the stimulus word shortly tilted 20° to the right for 300 ms before the screen turned black and the experimenter coded the actual response given by the subject. After coding, another 100 ms passed before the next trial started. In between two blocks, the participants were allowed a short, self-paced break.

RESULTS

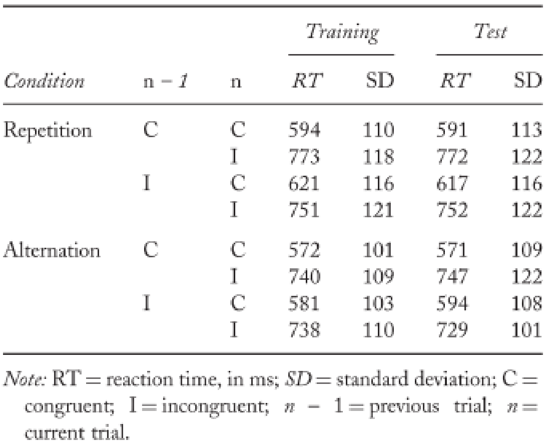
Again, we first subjected the data to a trimming procedure. A total of 5.3% of the data was excluded due to misses and false alarms caused by voice key malfunctioning. Then, trials on which participants made an error were eliminated, amounting to a total of 2.8%. Furthermore, the first trial of each block, as well as RT outliers (± 2.5 *SD*, calculated separately per condition, subject and congruency level) was removed (another 4.4% of the remaining data). Responses immediately following an error trial or non-response were eliminated as well (another 7.5%). Contrary to Experiment 1, slightly more congruent trials were removed (20% compared to 18% incongruent trials), but this was again proportional in both experimental conditions ($p > .05$). In sum, the data analysis was thus carried out on the remaining 81.3% of the trials.

We again performed a mixed-design ANOVA with the within-subject factors Experimental Phase (two levels: training and test), Previous Congruency (two levels: congruent and incongruent) and Current Congruency (two levels: congruent and incongruent) and the between-subject factor Experimental Condition (two levels: repetition and alternation). Firstly, a Stroop effect of similar size as in Experiment 1 (i.e., 157 ms) was found, $F(1, 28) = 284.79$, $p < 0.001$, that did not differ between the two experimental conditions, $F(1, 28) < 1$, *ns*. This congruency effect interacted significantly with the factor Previous Congruency, $F(1, 28) = 30.56$, $p < 0.001$, indicating an overall CSE. Importantly, the four-way interaction between experimental phase, congruency, previous congruency and experimental condition again turned out to be significant, $F(1, 28) = 4.48$, $p < 0.05$.

In the training phase, a significant interaction between previous and current congruency emerged, $F(1, 28) = 31.63$, $p < 0.001$. The higher-order interaction with condition, however, indicates that this CSE was much larger in the repetition condition compared to the alternation condition, $F(1, 28) = 11.76$, $p < 0.05$. As summarized in Table 3, the Stroop congruency effect in the repetition condition was strongly reduced after incongruent compared to congruent predecessors: a reduction from 179 ms to 130 ms, resulting in a CSE of 49 ms, *t*(14) = 6.84, $p < 0.001$. For the alternation condition, this reduction did not reach significance (a CSE of 11 ms, *t*(14) = 1.45, $p = 0.170$).

In the test phase, a significant CSE was again found, *F*(1, 28) = 21.7, $p < 0.001$, but contrary to the findings in the training phase, this effect did not vary significantly between the two experimental conditions, *F*(1, 28) < 1, *ns*. For both conditions, the Stroop effect was diminished following incongruent compared to congruent predecessors: in the repetition condition, the reduction from 181 ms to 135 ms was significant, *t*(14) = 3.21, $p < 0.01$. For the alternation condition, the comparable reduction from 176 ms following congruent trials to 135 following incongruent ones turned out significant as well, *t*(14) = 3.42, $p < 0.01$. Mean reaction times and standard deviations are presented in Table 3.

Table 3: Mean reaction times and standard deviations as a function of the congruency level of the previous and current trials for the training and test phases of the repetition and alternation conditions in Experiment 2.

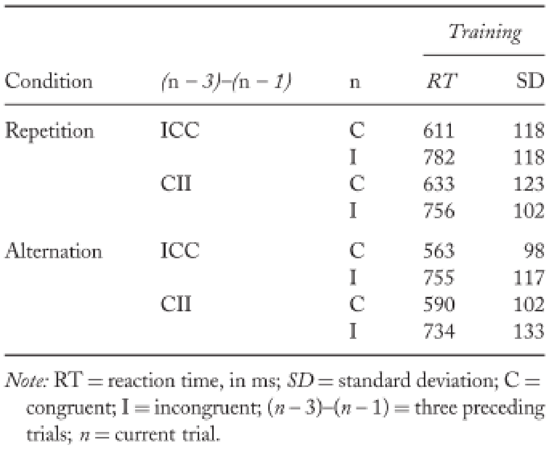


			Training		*Test*	
Condition	n − *1*	n	*RT*	SD	*RT*	SD
Repetition	C	C	594	110	591	113
		I	773	118	772	122
	I	C	621	116	617	116
		I	751	121	752	122
Alternation	C	C	572	101	571	109
		I	740	109	747	122
	I	C	581	103	594	108
		I	738	110	729	101

Note: RT = reaction time, in ms; *SD* = standard deviation; C = congruent; I = incongruent; *n* − 1 = previous trial; *n* = current trial.

Yet, this analysis does not take into account cumulative effects of longer series of repeated congruency level repetitions during the course of the training phase. Therefore, we again ran an extra mixed-design ANOVA on the same specific set of transitions within the training phase that are matched on recent conflict history. As in Experiment 1, we found a significant CSE within these trial transitions, $F(1, 28) = 11.91$, $p < 0.01$, that however did not interact with condition, $F(1, 28) < 1$, *ns*, again suggesting that recent conflict history affected reaction times more than repetition probability. Mean reaction times and standard deviations of this analysis are summarized in Table 4.

Table 4: Mean reaction times and standard deviations as a function of conflict history on the previous three trials and the congruency level of the current trial for the training phases of the repetition and alternation conditions in Experiment 2.

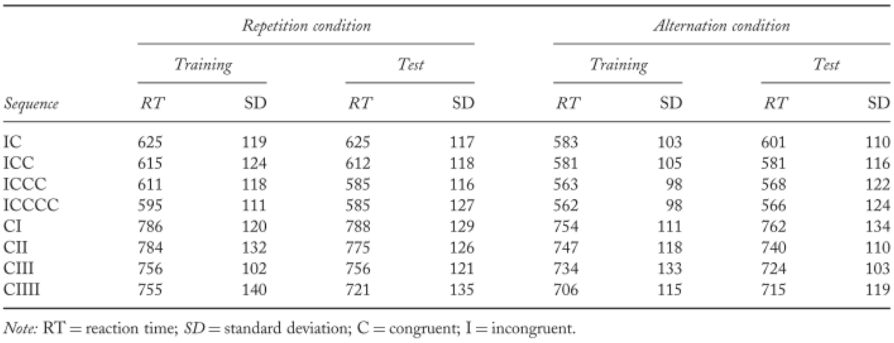


			Training	
Condition	*(n − 3)–(n − 1)*	n	*RT*	SD
Repetition	ICC	C	611	118
		I	782	118
	CII	C	633	123
		I	756	102
Alternation	ICC	C	563	98
		I	755	117
	CII	C	590	102
		I	734	133

Note: RT = reaction time, in ms; *SD* = standard deviation; C = congruent; I = incongruent; $(n - 3)–(n - 1)$ = three preceding trials; n = current trial.

In this view, reaction times should decrease as the amount of congruency level repetitions increases, irrespective of expectancies. To put this to the test, we ran a mixed-design ANOVA with the within-subjects factors Experimental Phase (two levels: training and test), Current Congruency (two levels: congruent and incongruent) and Repetition (the amount of congruency level repetitions following an alternation; four levels) and the between-subjects factor Experimental Condition (two levels: repetition and alternation). So for the training and test phases in both conditions, the following transitions entered the ANOVA: IC; ICC; ICCC; ICCCC and CI; CII; CIII; CIIII. The analysis revealed a significant main effect of Repetition, $F(3, 81) = 13.9$, $p < 0.001$, that did not interact with Experimental Phase, Current Congruency nor Experimental Condition, each $F(3, 81) < 1$, *ns*. In both conditions, participants' reactions to congruent or incongruent trials were progressively faster as the amount of preceding repetitions increased, even in the training phase of the alternation condition in which 70% of congruency level alternations were presented. Table 5 displays the mean reaction times and standard deviations to these sequences for both phases in each condition.

Table 5: Mean reaction times and standard deviations as a function of the amount of congruency level repetitions for the training ant test phases of the repetition and alternation conditions in Experiment 2.



	Repetition condition				*Alternation condition*			
	Training		*Test*		*Training*		*Test*	
Sequence	*RT*	SD	*RT*	SD	*RT*	SD	*RT*	SD
IC	625	119	625	117	583	103	601	110
ICC	615	124	612	118	581	105	581	116
ICCC	611	118	585	116	563	98	568	122
ICCCC	595	111	585	127	562	98	566	124
CI	786	120	788	129	754	111	762	134
CII	784	132	775	126	747	118	740	110
CIII	756	102	756	121	734	133	724	103
CIIII	755	140	721	135	706	115	715	119

Note: RT = reaction time; *SD* = standard deviation; C = congruent; I = incongruent.

DISCUSSION

Similar conclusions can be drawn from the results of the second experiment. On the one hand, the significant CSE provides further evidence for an interpretation in terms of attentional control. On the other hand, as was the case in Experiment 1, the frequency manipulation did have an impact on the size of the CSE, but this difference did not transfer to the unmanipulated test phase. Further analyses showed that the same trial-to-trial dynamic adjustments influenced Stroop performance in the training phase, irrespective of the expectancy manipulation in the two conditions. Taken together, the results thus again suggest that reactive control processes dominate adaptive behavioural adjustments within the Stroop conflict task.

GENERAL DISCUSSION

In two experiments, we critically contrasted the *repetition expectancy* and *conflict monitoring account* for the CSE, while controlling for the *feature integration account*. By administering a vocal Stroop task without stimulus feature repetitions, we first verified whether the Gratton effect would still emerge when episodic memory effects are controlled for. In order to investigate the role of congruency level expectancy in bringing about this effect, we manipulated participants' expectancies for the congruency sequence by raising the amount of either congruency level repetitions or alternations. The results revealed two interesting effects.

ATTENTIONAL CONTROL VERSUS EPISODIC MEMORY

First, the finding of a significant CSE throughout the two experiments can be seen as strong evidence for an underlying cognitive control mechanism, as episodic memory effects were controlled for. By using a vocal Stroop task with eight different colours, we were able to leave out trials with stimulus feature repetitions prior to the testing while keeping the response mapping intuitive. This enabled us to evaluate the contribution of cognitive control processes more clearly and elegantly than previous attempts. Other studies that applied the strategy of expanding the stimulus set face the disadvantages of further complicating the response mapping as well as losing a lot of data after exclusion of trial transitions involving stimulus feature overlap. Moreover, the studies that have followed this logic drew some remarkably inconsistent conclusions. On the one hand, a series of studies reported no remaining sign of a CSE after post hoc exclusion of response or feature repetitions in various variants of the flanker (Mayr et al., 2003; Nieuwenhuis et al., 2006) or Simon (Chen & Melara, 2009) paradigm. On the other hand, other studies still observed a CSE for a subset of trial transitions with an equal amount of stimulus feature overlap (Wühr, 2005) or when analyzing specific transitions where stimulus or response features alternated (Kerns et al., 2004; Kunde & Wühr, 2006; Ullsperger, Bylsma, & Botvinick, 2005).

Problems with this experimental control approach were summarized by Notebaert and Verguts (2007). They argued that the main difficulty lies in the lack of consensus about how the selection of trials should be implemented. As discussed above, one can either exclude only complete repetitions, or continue excluding partial repetitions too. Notebaert and Verguts (2006) as well as Akçay and Hazeltine (2007) went even further by also excluding negative priming transitions, in which the distractor of the previous trial becomes the target on the current trial. The practice of expanding the stimulus set and then excluding more and more potential bottom-up confounds does not only lead to unnecessarily complicating the experimental design and response mapping, but also to the removal of more and more data from the analyses. Consequently, another issue arises: the decision on the presence or absence of sequential effects has to be made on a very limited and thus special subset of trial transitions in which absolutely no feature is repeated. Notebaert and Verguts (2007) proposed a multiple regression solution to this problem, statistically separating the influences of stimulus feature repetition and top-down control. In this study, we got around this issue by presenting only trial transitions in which no stimulus features repeated while keeping the response mapping intuitive. Therefore, we were able to avoid the methodological and theoretical shortcomings and conclude that a CSE still emerges in the complete absence of potentially confounding episodic memory effects.

It should be noted that even for sequences with no repeated stimulus features, episodic effects of feature integration and retrieval cannot be overlooked (Dutzi & Hommel, 2009). According to the Theory of Event Coding (TEC; Hommel et al., 2001), reaction times in decision-making tasks are essentially depending on the competition between candidate codes. In the case of stimulus alternations, the theory claims that the binding of competing stimulus and response features on the previous trial that are unrelated to the present stimulus and response features will facilitate, through the workings of ‘integrated competition’, handling the current trial. When stimuli are alternated, binding processes will thus bias behaviour towards response alternations. Since in the present design all trial transitions involve a complete stimulus alternation, these processes are however held constant throughout the experiment. Therefore, control processes rather than episodic memory effects seem critically involved in the variations in the CSE found in the experiments.

The fact that CSEs are observed in the absence of stimulus feature repetitions does however not imply that the feature integration hypothesis should be rejected: both accounts are far from mutually exclusive, but rather influence performance simultaneously. In a three-colour Stroop experiment, Notebaert et al. (2006) showed that bottom-up modulation and top-down control additively contributed to the reported CSE. The size of this conflict adaptation on complete alternation trials (in the absence of any feature integration effects) was found to be smaller than on partial repetition trials (entailing feature integration effects). By means of a response-stimulus-interval (RSI) manipulation they further differentiated both influences, showing that attentional control modulation only occurred with relatively long RSI’s, while bottom-up repetition effects were found for both the short and long RSI’s. In later theorizing, Verguts and Notebaert (2008; 2009) proposed an associative cognitive control model to capture both conflict-modulated control and binding processes.

PROACTIVE VERSUS REACTIVE CONTROL

A second important contribution of this study is that we observed evidence for reactive, conflict-induced control adjustments irrespective of congruency level expectations. By either raising or reducing the amount of congruency repetitions during a training phase, we aimed to respectively confirm or discourage participants' repetition expectancy. Over the two experiments, the same pattern of results emerged. In each of the manipulated phases, the size of the CSE was much larger in the repetition condition compared to the alternation condition, but this seemed mainly due to cumulative effects of longer series of congruency level repetitions. Further analyses revealed that even within the alternation condition, in which expectancies were biased towards congruency level alternations, reactions to both congruent and incongruent trials were increasingly faster when the amount of preceding congruency level repetitions increased. The lack of a transfer effect from the training to the test phase, in which a CSE of comparable size was found for both conditions, further suggested that the amount of conflict (or lack thereof) in the recent trial history is driving these control adjustments.

In this view, it seems that raising the amount of congruency level repetitions not only induced differential expectancies about the upcoming trial, but also changed reactive control processes, as captured in the models of Botvinick et al. (2001) and Verguts and Notebaert (2008; 2009). In the case of longer series of repeated congruent trials, for instance, the amount of conflict and thus control settings will become increasingly lower. As a consequence, the irrelevant stimulus dimension influences response selection more heavily, so that ICCC transitions will lead to faster reaction times on the final congruent trial compared to ICC trial transitions. A sequence of repeated incongruent trials, on the other hand, magnifies the amount of conflict in the system, leading to tighter control settings and a strong focus on the relevant stimulus dimension, resulting in faster reactions to the final incongruent trial in CIII transitions compared to CII trial sequences.

Interestingly, a recent alternative theoretical framework of Schlaghecken and Martini (2011) also pointed out the importance of the context for adaptive behaviour. According to their model, the visuo-motor system continuously adapts to the situational demands by tightening or relaxing its responsiveness in a context-dependent fashion, rather than through a conflict detecting and resolving mechanism. The authors stress that adjustments following congruent (and thus conflict-free) trials are more frequently and robustly observed in the literature. In a series of three experiments, they found that trial-type repetition benefits were much more pronounced for congruent than incongruent trials, irrespective of expectancies (as similar results were obtained when the proportion of congruent trials was manipulated). Over the two experiments presented here, the trial-type repetition effect (calculated separately for each phase and condition) was indeed numerically larger for congruent compared to incongruent trials, but not statistically so (all *p*s > .05). Moreover, analysis of the repeated sequences in Experiment 2 revealed that reaction times decreased linearly with each consecutive repetition to the same extent for congruent and incongruent trials.

In a recent paper, Egner, Ely, and Grinband (2010) also questioned explanations of the CSE in terms of proactive, epxectancy-guided preparatory biasing on the basis of their findings in two studies that systematically varied the size of the inter-stimulus-interval (ISI, between 500 and 7000 ms) or response-stimulus-interval (RSI, between 500 and 5000 ms). In their view, a proactive, expectancy-based account would assume the preparatory processes to grow stronger over time, leading to a more pronounced CSE with increasing intervals. However, the size of the CSE steadily diminished with increasing intervals, and was completely absent at the longer intervals in both experiments. According to the authors, an explanation in terms of a conflict adaptation process with a fairly steep and time-bound decay function best fitted the data. Even though stretching the presentation of the fixation dot from 500 ms (Experiment 1) to 2000 ms (Experiment 2) did not diminish the size of the Gratton effect in the current studies (44 ms and 49 ms, respectively), the experiments of Egner and colleagues (2010) also suggest that conflict level expectancies do not drive control adjustments in regular conflict tasks.

Yet, contrary to our findings, other recent studies do report evidence for the idea that information from internal sources can strategically optimize attention allocation in anticipation of the specific to-be-expected difficulty of the upcoming task. Rather than manipulating repetition expectancy, Wendt and Kiesel (2011) manipulated associations between stimulus foreperiods of different length and the proportion of conflict trials. When the long foreperiod was associated with an 80% chance of an incongruent trial, the authors found a reduced flanker interference effect compared to the short foreperiod associated with 20% conflict trials. They suggest that participants use the foreperiod as a contextual cue steering attentional adjustments, and re-adjust their attentional set during the trial dependent on the expected difficulty of the upcoming condition. Expectancy-based attentional control has also recently been suggested to drive proportion congruency effects (to some extent; Bugg & Chanani, 2011), and has been well investigated in several experiments in which the upcoming congruency level was cued (Aarts & Roelofs, 2011; Correa, Rao, & Nobre, 2009).

In light of these results, it remains a question for further research which conditions call for proactive, expectancy-based adjustments in the attentional weighting of perceptual dimensions, and in which situations participants rely more heavily on reactive control processes. One potential answer is given by the dual mechanisms of control theory (Braver, Gray, & Burgess, 2007), that suggests that a proactive control strategy is presumably very resource demanding and metabolically costly, whereas reactive control processes are less capacity-demanding and more readily available. Moreover, according to that theoretical framework, a proactive control strategy requires predictive contextual cues that are highly reliable. As participants in our experiments were not informed or explicitly cued about the transitional probabilities, they might have refrained from adopting a metabolically costly proactive control strategy. However, future research is needed to further disentangle situations that elicit a proactive control strategy more heavily from situations in which reactive control processes are dominant.

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CHAPTER 3
THE HOT-HAND FALLACY IN COGNITIVE CONTROL: REPETITION EXPECTANCY MODULATES THE CONGRUENCY SEQUENCE EFFECT[1]

In this study, the role of expectancies in cognitive control was tested. On the basis of the original interpretation of the congruency sequence effect (Gratton, Coles, & Donchin, 1992), we sought evidence for a repetition bias steering attentional control. In a series of four Stroop experiments, we investigated how participants' explicit predictions about the upcoming (in)congruency proactively influenced subsequent Stroop performance. Similar to the fallacious hot-hand belief in gambling, repeating stimulus events were overpredicted, as participants consistently expected more repetitions of the congruency level than the actual presented number of congruency level repetitions (50%). Moreover, behavioural adjustments (i.e., a congruency sequence effect) were only found when participants anticipated a congruency level repetition, whereas no modulation of the Stroop effect was found following alternation predictions. We propose that proactive control processes in general, and repetition expectancy in particular, should be given more attention in current theorizing and modelling of cognitive control, which is characterized by an emphasis on reactive, conflict-induced control adjustments.

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[1] This chapter is based on: Duthoo, W., Wühr, P., & Notebaert, W. (2013). The hot-hand fallacy in cognitive control: Repetition expectancy modulates the congruency sequence effect. *Psychonomic Bulletin & Review,* 1-8.

INTRODUCTION

Cognitive control allows us to adaptively adjust to an ever-changing environment. Therefore, the cognitive system not only monitors the environment, it also generates predictions. Research has predominantly focused on the monitoring aspect, by studying reactive, post-conflict adjustments. Recent influential models (e.g., Alexander & Brown, 2011) have stressed the importance of learning on the basis of prediction-driven outcomes. Still, experimental work on how expectancies can steer attentional control is relatively scarce.

Human predictions themselves have been widely investigated. Kahneman, Slovic, and Tversky (1982), for instance, convincingly showed that predictions are inherently biased. When predicting random events, people often expect too many alternations (Nickerson, 2002). Faced with a run of ‘heads’ in coin tossing, for example, the gambler will believe that the run will be broken (*the gambler’s fallacy*). On the other hand, one expects a winning poker player to keep on winning (*the hot-hand fallacy*). According to Kareev (1995), human predictive behaviour reveals a tendency towards expecting repeating events, in line with the hot hand fallacy.

These biased predictions can influence reaction times (RTs) in relatively simple tasks. In serial two-choice RT tasks, for example, responses to stimulus repetitions are typically faster than responses to stimulus alternations (e.g., Remington, 1969). Soetens, Boer, and Hueting (1985) explained this repetition effect in terms of subjective expectancy. However, once the inter-trial-interval was sufficiently stretched, Soetens et al. demonstrated an alternation effect, corresponding to faster responses to different than to repeated stimuli. These authors assumed that, in accordance with the gambler’s fallacy, participants expect too many alternations in a random run of binary stimuli.

According to Gratton, Coles, and Donchin (1992), biased expectancies also drive the congruency sequence or *Gratton* effect. Applying a flanker task, in which participants have to react to the central target flanked by either congruent (<<<) or incongruent (><>) flankers, they found a reduced congruency effect after incongruent trials. The authors theorized that these sequential modulations reflect strategic adjustments in cognitive control. Gratton et al. presumed a congruency repetition bias: Despite objectively equal chances of encountering a congruent (C) or an incongruent (I) trial, participants tend to expect easy (congruent) trials after easy trials, and difficult (incongruent) trials after difficult trials. Participants strategically narrow attention to the central target when anticipating an incongruent stimulus, thereby minimizing the impact of the misleading flankers. In anticipation of a congruent trial, participants broaden their attentional focus, so that the congruent flanking information is allowed to contribute more to response selection. This proactive, expectancy-based regulation of attentional strategies leads to faster responses on trial transitions involving a congruency level repetition (i.e., on CC and II trial transitions). When expectancies are violated (i.e., on CI and IC trial transitions), these preparatory adjustments backfire and impair performance in terms of slower responses or higher error rates.

A recent test did not support the existence and influence of such a congruency level repetition bias. Jiménez and Méndez (2013) interleaved blocks of standard Stroop trials with blocks in which participants were asked to indicate which trial (congruent or incongruent) would come next. The results revealed that participants fell into the gambler's fallacy after only one sequence of repeated congruency. Moreover, analysis of the separate Stroop blocks suggested a dissociation between expectancies and performance: Following sequences of repeated congruency, performance benefitted from a congruency level repetition, despite an expectancy for congruency level alternations.

Since evidence supporting the proactive repetition expectancy account is rather scarce, the congruency sequence effect (CSE) is predominantly conceptualized in terms of *reactive*, conflict-induced adjustments (Botvinick, Braver, Barch, Carter, & Cohen, 2001). According to a reactive account, the detection of response conflict on incongruent trials leads to a temporary up-regulation in the control settings, enhancing the processing of task-relevant stimulus information, irrespective of participants' expectancies for the upcoming trial.

In the present article, we aimed to investigate the impact of expectancies on attentional control more directly, by presenting participants with a vocal Stroop task and asking them explicitly to predict the congruency level of the upcoming Stroop trial. Contrary to Jiménez and Méndez (2013), we measured predictions and performance on the same trials.

We predicted a repetition bias, in the sense that participants would expect the congruency level of the last encountered trial to repeat on the next trial. We also investigated the influence of these predictions on task performance, by calculating the CSE separately for repetition expectancies and alternation expectancies. Importantly, while a proactive account predicts a repetition bias and an influence of these predictions on subsequent task performance, a reactive account does not.

EXPERIMENTS 1A AND 1B

In Experiment 1A, we ran an eight-colour Stroop task in which participants were asked to try to predict the congruency level before the actual presentation of the colour word. We verified whether participants were biased to expect repeated congruency level in successive trials and probed how the CSE is influenced by this repetition expectancy. In order to assess a pure measure of the CSE, we constrained random selection of the colour word and colour so that no stimulus feature was repeated relative to trials *n*-1 and *n*-2 (see also, e.g., Duthoo & Notebaert, 2012). In the otherwise identical Experiment 1B, we used only four colours and allowed complete and partial stimulus feature repetitions. Apart from verifying the replicability of our results, we also tested how these stimulus feature repetitions influenced predictions.

METHOD

Participants. A group of 15 Ghent University students (11 females, four males; ages 18-24 years) provided written informed consent to participate in Experiment 1A. Another fifteen (12 females, three males; ages 18-25 years) were recruited for Experiment 1B.

Stimuli and Apparatus. Stimuli were displayed on a 17-inch monitor, with a viewing distance of approximately 50 cm. In Experiment 1A, the stimuli consisted of eight (Dutch) colour words printed in one of the eight possible colours (red, green, blue, yellow, pink, brown, purple, or grey). For Experiment 1B, the selection of colours and colour words was restricted to red, green, blue, and yellow. All text was presented in Courier font, size 20. Participants had to react by saying out loud the font colour, and responses were detected by means of a Sennheiser MD 421-U-4 microphone.

Design and Procedure. Equal numbers of congruent and incongruent trials were presented. In Experiment 1A, we constrained random selection of the colour and colour word by precluding complete stimulus repetitions or relevant or irrelevant feature repetitions, relative to both trials *n*-1 and *n*-2. In other words, all stimulus and response features changed across three consecutive trials. For Experiment 1B, random selection of the colour and colour word was unconstrained, allowing complete and partial stimulus feature repetitions.

Participants were presented with a practice block of 90 regular Stroop trials. The participants then completed a second practice block containing 15, during which they not only had to predict the congruency of the upcoming trial by clicking the left or the right mouse button (counterbalanced across participants), but also to report afterwards whether or not their prediction was confirmed, again by mouse click. The data revealed that the participants understood the basic idea of the experiment, since all participants judged their predictions accurately above chance level.

Finally, four experimental blocks of 90 trials were presented, during which participants had to make predictions about the difficulty of the upcoming stimulus and subsequently to respond accurately to it.

Each experimental trial started with the presentation of a fixation dot for 500 ms, followed by an instruction (‘Next trial?’) that remained visible until participants clicked one of the mouse buttons. Then, the screen turned black for 1000 ms, after which the Stroop trial appeared on screen until a response was registered by the microphone (max 2000 ms). The moment that the voice key was triggered, the stimulus word shortly tilted 20° to the right for 300 ms before the screen turned black and the experimenter coded the actual response given by the participant. When the voice key was triggered too early (caused by a noise other than the participant’s voice) or too late (because of the participant hesitating, hissing or raising his or her voice during the response), the experimenter coded the trial as a false alarm. After coding, another 500 ms passed before the next trial began. No error feedback was provided.

RESULTS

Data cleaning. We excluded one participant from Experiment 1A for not engaging in the prediction task (by ‘predicting’ all trials to be incongruent). Then, we removed the first trial of each block and all trials containing misses and false alarms caused by voice key malfunctioning (Exp. 1A, 11.7%; Exp. 1B, 8.2%). Next, error trials (Exp. 1A, 2.6%; Exp. 1B, 2%) and trials with extreme RTs (<300 ms and >1500 ms; Exp. 1A, 0.71%; Exp. 1B, 1.3%) were removed. Finally, responses following an error trial or non-response (Exp. 1A, 10.7%; Exp. 1B, 7.7%) were also excluded.

Prediction performance. On average, participants’ predictions matched the congruency level of the previous trial on 65% of their choices in Experiment 1A, and on 62% of their choices in Experiment 1B. A paired-samples *t*-test revealed that these percentage were significantly larger than the actual numbers of presented congruency level repetitions in both Experiment 1A [50% on average, $t(13) = 6.41$, $p < .001$ and Experiment 1B (49%; $t(14) = 4.66$, $p < .001$]. For Experiment 1B, this congruency level repetition bias was not different following exact repetitions (59%), relevant feature repetitions (60%), or irrelevant feature repetitions (62%), all *p*s > .2. Contrary to the findings of Jiménez and Méndez (2013), we observed an even stronger repetition bias when the previous sequence (*n*-2 to *n*-1) had entailed a congruency level repetition than when the previous sequence had entailed a congruency level alternation. This difference was significant for Experiment 1A (69% vs. 62%, $t(13) = 2.31$, $p < .05$), yet only marginally significant for Experiment 1B (65% vs. 60%, $t(14) = 1.88$, $p = .082$).

Reaction times. We ran a repeated-measures analysis of variance (ANOVA) with the within-subject factors Repetition Expectancy (two levels: repetition and alternation), Previous Congruency (two levels: congruent and incongruent), and Current Congruency (two levels: congruent and incongruent). As is depicted in Figure 1, a significant three-way interaction was found in both Experiment 1A, $F(1, 13) = 20.02$, $p < .001$, and 1B, $F(1,14) = 13.92$, $p < .01$. When participants expected a repetition of congruency level, a significant interaction between previous and current congruency (i.e., a CSE) was found [Exp. 1A, $F(1, 13) = 45.05$, $p < .001$; Exp. 1B, $F(1, 14) = 41.26$, $p < .0001$], that was completely absent when an alternation of congruency level was expected [Exp. 1A: $F(1, 13)<1$; Exp. 1B: $F(1, 14) < 1$].

Error percentages. For Experiment 1A, only the main effect of Current Congruency turned out to be significant, $F(1, 13) = 20.12$, $p < .001$. Neither the three-way interaction, nor the interaction between Previous and Current Congruency, reached significance, $F(1, 13) < 1$. For Experiment 1B, the main effect of Current Congruency, $F(1, 14) = 10.47$, $p < .01$, as well as the interaction between Current and Previous Congruency, $F(1, 14) = 12.73$, $p < .01$, turned out significant. Contrary to our predictions, the three-way interaction between Repetition Expectancy and Previous and Current Congruency was not significant, $F(1, 14) = 2.35$, $p = .148$, indicating similar

CSEs after repetition and alternation predictions (see Figure 1). However, we would stress that these results have to be interpreted with caution, since overall error rates were low and response errors could not be dissociated from technical errors. Still, the results at least suggest that the RT effects were not due to a speed-accuracy trade-off. Experiment 2A and 2B, in which manual responses were registered, were better suited for investigating error rates.

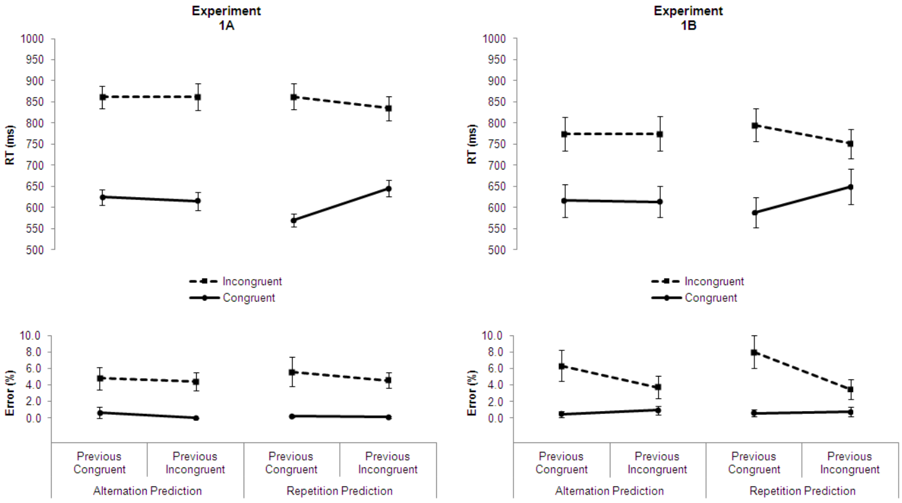

Figure 1: Mean reaction times (RTs, in milliseconds) and error percentages for incongruent (dashed line) and congruent (solid line) trials of Experiment 1A and Experiment 1B as a function of the congruency level of the previous trial, separately for repetition and alternation predictions. Error bars represent 95% confidence intervals around the mean.

DISCUSSION

Experiments 1A and 1B provided evidence for an influence of predictions on cognitive control, unaffected by stimulus and/or response sequences. Both experiments, however, artificially increased the congruency rate to 50%, so that congruent trials occurred more often than they would have if features had been selected randomly (i.e., 12.5% in Exp. 1A and 25% in Exp. 1B). As Mordkoff (2012) argued, increasing the proportion of congruent trials makes the irrelevant task dimension (i.e., the colour word in the Stroop task) informative (see also Dishon-Berkovits & Algom, 2000). As a consequence, participants might have been encouraged to pay more attention to the distractor word. In order to verify whether the results of the previous two experiments would replicate when the irrelevant word dimension did not predict the target colour, we ran a similar two-choice version of the Stroop task, in which every word-colour combination was presented equally often (Experiment 2A). Moreover, we now ran a manual version of the Stroop task that enabled a proper error analysis in the absence of the technical confounds (i.e., voice key errors) associated with our voice key procedure.

In order to further investigate the discrepancy between our findings of a bias towards repetitions of the same congruency level over successive trials and recent results of Jiménez and Méndez (2013), showing a bias towards alternations after one repetition, we also ran a second version of the experiment (Exp. 2B) that more closely resembled the procedure applied by Jiménez and Méndez.

EXPERIMENTS 2A AND 2B

We tested whether the findings reported above would replicate in a two-choice manual version of the Stroop task (Experiment 2A). We also ran an otherwise identical Experiment 2B in which the expectation measure applied by Jiménez and Méndez (2013) was copied. Instead of the categorical decision about the congruency level of the upcoming trial, we asked participants to indicate whether they were sure, fairly sure, or guessing that the next trial would be congruent or incongruent. Apart from these differences, the methods and procedures of Experiments 2A and 2B were identical to those of the previous experiments.

METHOD

Participants. A group of 15 Ghent University students (13 females, two males; ages 18-23 years) provided written informed consent to participate in Experiment 2A. Another fifteen (13 females, two males; ages 18-23 years) were recruited for Experiment 2B.

Stimuli and apparatus. The Stroop stimuli were restricted to the words ‘ROOD’ (Dutch for ‘red’) and ‘GROEN’ (Dutch for ‘green’) presented in either red or green. Participants had to react to the font colour by pressing the ‘S’ or the ‘D’ key on a QWERTY keyboard for red or green, respectively.

Design and Procedure. Following the practice block of 90 trials, participants in Experiment 2A were asked to predict whether the upcoming trial would be easy (congruent) or difficult (incongruent) by pressing the ‘4’or the ‘6’ key on the numeric keypad. The mapping of congruencies to the number keys was counterbalanced across participants. The participants in Experiment 2B were asked to indicate their congruency level prediction by pressing the appropriate key on the numeric keypad corresponding to one of the six points of a Likert scale, ranging from *sure easy* (‘1’ key) over *fairly sure easy* (‘2’ key), *guess easy* (3 ‘key’), *guess difficult* (4 ‘key’) and *fairly sure difficult* (5 ‘key’) to *sure difficult* (6 ‘key’). In order to make sure that both this extra task and its response mapping were clear, participants in both experiments first completed a practice block containing ten trials, during which they not only had to predict the upcoming trial, but also report afterwards whether or not their prediction was confirmed, by clicking the ‘7’ (*yes*) or ‘9’ (*no*) key. On the basis of the accuracy of these judgements, one participant whose performance did not exceed chance level was excluded from the analysis in both experiments. Hereafter, four blocks of 80 trials were presented, during which participants had to make predictions about the difficulty of the upcoming stimulus and respond to it accurately.

RESULTS

Data cleaning. For both experiments, we excluded one participant who did not engage in the prediction task (by ‘predicting’ all trials to be incongruent in three [Exp. 2A] or four [Exp 2B] of the four experimental blocks) and another participant who did not grasp the basic idea of the experiment, as evidenced by bad performance in the practice block reported above. Then we removed the first trial of each block as well as all trials on which participants failed to respond within the response deadline (Exp. 2A, 3.1%; Exp. 2B, 4%), error trials (Exp. 2A, 4.4%; Exp. 2B, 8.7%) as well as trials with extreme RTs (<200 ms and >1200 ms; another 2.9% [Exp. 2A] and 5.5% [Exp. 2B]) and trials following an error trial or null response (Exp. 2A, 5%; Exp. 2B, 8.1%).

Prediction performance. On average, participants’ predictions matched the congruency level of the previous trial on 56% of their choices in Experiment 2A. A paired-samples *t*-test revealed that this percentage exceeded the actual number of congruency level repetitions presented to the participants [i.e., 50%, $t(12) = 2.98$, $p < .05$]. In order to compare the prediction pattern of Experiment 2B with that of the previous experiments, we first ran a similar analysis by recoding the Likert scale scores back into categorical congruent or incongruent predictions. On average, the participants’ predictions matched the congruency level of the previous trial on 58% of their choices, significantly exceeding the actual number of congruency level repetitions presented to the participants [i.e., 50%; $t(12) = 2.78$, $p < .05$].

We ran a second analysis on these expectancy scores collected in Experiment 2B, after recoding *guess*, *fairly sure* and *sure congruent* responses into scores of 1, 2, and 3, respectively, and *guess*, *fairly sure* and *sure incongruent* into -1, -2, and -3, respectively (e.g., similar to the procedure of Jiménez & Méndez, 2012). The factor Context coded the number of congruent or incongruent predecessors to a trial, ranging from one to three congruent (C) or incongruent (I) trials. A repeated-measures

ANOVA with the factor Context (six levels: 3C, 2C, 1C, 1I, 2i, 3I) was performed on the choice data. The results revealed a significant effect of the preceding context, $F(5, 60) = 5.46$, Huynh-Feldt corrected $p < .05$. As is depicted in Figure 2, participants' expectations tended more strongly towards a congruent trial following one, two or three congruent trials than following one, two, or three incongruent trials, and vice versa (all p-values < .05). Moreover, the expectancy ratings did not differ between one, two or three consecutive congruent or incongruent trials (all ps > .13).

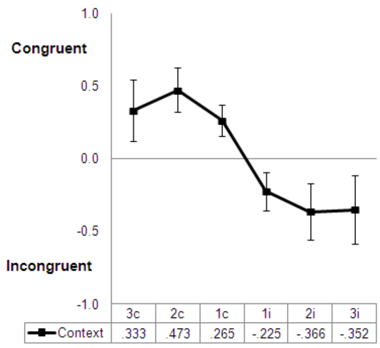

Figure 2: Mean averaged expectancy scores of Experiment 2B as a function of the preceding context, ordered from three congruent predecessors to three incongruent predecessors. Postive values denote increased expectancy for an upcoming congruent trial, whereas negative values denote increased expectancy for an upcoming incongruent trial. These values are summarized in the table below the figure. Error bars represent 95% confidence intervals around the mean.

Reaction times. A significant three-way interaction between Repetition Expectancy, Previous Congruency and Current Congruency was found in both Experiments 2A, $F(1, 12) = 15.46$, $p < .01$, and 2B, $F(1, 12) = 6.33$, $p < .05$, after collapsing expectancy scores into a categorical predictions (see Figure 3). When participants expected a repetition of the congruency level, a significant interaction between previous and current congruency (i.e., a CSE) was found [Exp. 2A, $F(1, 12) = 17.84$, $p < .001$; Exp. 2B, $F(1, 12) = 21.88$, $p < .001$], that was completely absent when an alternation of congruency level was expected [*F*s(1, 12) < 1, in both experiments].

Error percentages. As in the RT analysis, a three-way interaction emerged that was significant in Experiment 2A, *F*(1, 12) = 7.93, *p* < .05, yet only marginally significant in Experiment 2B, *F*(1, 12) = 4.01, *p* = .068 (see Figure 3). In anticipation of a congruency level repetition, a significant CSE was found [Exp. 2A, *F*(1, 12) = 6.17, *p* < .05; Exp. 2B, *F*(1, 12) = 7.14, *p* < .05], that was completely absent when an alternation of congruency level was expected [*F*s(1, 12) < 1 in both experiments].

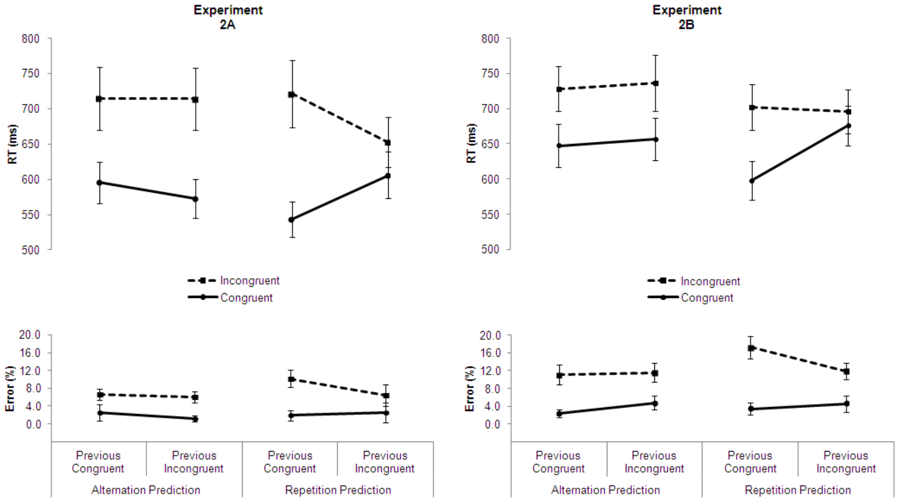

Figure 3: Mean reaction times (RTs, in milliseconds) and error percentages for incongruent (dashed line) and congruent (solid line) trials of Experiment 2A and Experiment 2B as a function of the congruency level of the previous trial, separately for repetition and alternation predictions. Error bars represent 95% confidence intervals around the mean.

GENERAL DISCUSSION

In a series of four experiments, we asked participants to predict the congruency level of the upcoming Stroop trial. The results revealed that participants expected the congruency level to repeat in the majority of the trials, and that participants' predictions influenced their subsequent task performance: Only when they predicted a congruency level repetition, was a congruency sequence effect (CSE) observed. These results were found in two-, four- and eight-colour Stroop tasks.

EXPECTANCY BIAS

The observed congruency repetition bias confirms the assumption that Gratton et al. (1992) took for granted. In line with the hot hand fallacy, participants expected a positive autocorrelation when none was actually present. This finding stands in contrast to studies that have shown an alternation bias in the perception, prediction, and generation of randomness (Nickerson, 2002). In the present task, participants were asked to predict the upcoming event as accurately as possible, and thus were implicitly encouraged to look for a systematic relationship between successive trial events. Thus, even though the trials were generated in a random fashion, participants still believed that the sequence was essentially nonrandom. Therefore, finding a repetition bias in the present experiments does not come as a surprise, as we have assumed (in line with Kareev, 1995) that repetition expectancy is an inherent preference aiding the search for meaningful (i.e., causal) relations in everyday life, one that is overcompensated for by an alternation bias when people are asked to evaluate or produce series of random events.

EXPECTANCY IN COGNITIVE CONTROL

More important to our understanding of cognitive control processes, our study revealed that repetition expectancies had a crucial impact on subsequent performance. Our results revealed sequential adjustments in the size of the Stroop effect only when participants predicted a repetition of congruent or incongruent trials. According to the *repetition expectancy account* (Gratton et al., 1992), participants strategically focus or widen attention on the basis of their implicit expectations of the congruency level to repeat. The results of our study both support and qualify this account, by showing that a CSE was present when participants explicitly expected a congruency repetition, and that no performance adjustments occurred when participants expected a change in congruency.

Traditional *reactive* models, such as the conflict monitoring model (Botvinick et al., 2001), do not predict an influence of repetition expectancy on the size of the CSE: Following conflict trials, and irrespective of participants' expectancy of the upcoming trial, task focus is up-regulated to overcome potential conflict on the subsequent trial. Therefore, a purely reactive account would predict CSEs of similar size following repetition and alternation predictions. In line with the dual-mechanisms-of-control framework (Braver, 2012), our results suggest that proactive, expectancy-based control processes can complement or dominate more automatic, reactive control mechanisms in response to situational demands. In the present experiments, explicitly probing for participants' expectancies might have triggered these proactive control strategies.

The present results might reflect the net effect of simultaneously operating control processes, one preparatory and proactive and the other conflict-induced and reactive. According to this view, preparatory control entails focusing more strongly on the colour in expectation of an incongruent trial, or allowing the word reading process to contribute more strongly to response selection in anticipation of a congruent trial. In contrast, reactive conflict regulation entails increasing controlled colour processing following incongruent trials, and decreasing this controlled colour processing after congruent trials (Botvinick et al., 2001). When combined, proactive and reactive control processes will complement each other following repetition predictions, producing a strong CSE. Following alternation predictions, however, both control adjustments will work in opposite directions, thereby cancelling each other out, reflected in the absence of sequential performance adjustments.

Alternatively, our data pattern can be explained in terms of within-trial control adjustments that carry over to the next trial for repetition expectancies, but not for alternation expectancies. More specifically, we put forward that participants adaptively focus attention during the processing of incongruent trials, reflecting reactive conflict adaptation processes as for instance described in Ridderinkhof (2002). This change to the attentional control settings is maintained for the next trial only if participants expect the congruency level to repeat, resulting in smaller congruency effects after incongruent than after congruent trials. This indicates a proactive attentional control process based on congruency level expectancies. If, however, participants expect the congruency level to alternate, they change their attentional control settings to an intermediate ‘default’ mode, thereby eliminating the CSE. In a similar vein, King and colleagues (2012) showed in a recent fMRI investigation of the context-specific proportion congruency (CSPC) effect that this CSPC effect emerged only when the context repeated from the previous to the current trial, but not when the context alternated between successive trials. In other words, the attentional control settings that were triggered by the context applied forward to the subsequent trial, but only when this context was repeated.

In contrast to our findings of an increased congruency level repetition bias following two consecutive trials of the same type, in a recent study Jiménez and Méndez (2013) reported evidence suggesting that participants already tended to fall into a gambler’s fallacy after only one sequence of repeated congruency. In an attempt to clarify this discrepancy, we set up an experiment that bridged the methodological gap between the two studies, by implementing a six-point Likert scale measure of congruency predictions similar to that of Jiménez and Méndez. Just as in their study, this procedure produced scores that did not diverge much from the 0 score, reflecting pure guessing. The pattern of expectancy scores (see Figure 2), however, was qualitatively different: Participants tended to expect a repeated congruency level following one, two or three congruent or incongruent trials. Moreover, whereas Jiménez and Méndez only found a significant CSE when taking into account the previous two or more trials (i.e., a progressive CSE), showing RT benefits in the opposite direction from expectancies, we found a robust CSE following repetition predictions when taking into account only one preceding trial. In other words, expectancies, and not previous context, seemed to have driven the behavioural adaptation. We suspect that in the study of Jiménez and Méndez the response-stimulus interval of 0 ms in the blocks in which no predictions were measured left no room for participants to prepare for what they expected. At a theoretical level, these differences can be interpreted in terms of the dual mechanisms of control theory (Braver, 2012): Whereas the methodology of Jiménez and Méndez's study mainly probed fast, conflict-induced reactive control processes, our prediction experiments might have triggered (additional) strategic, expectancy-based proactive control processes.

This also brings us to a possible limitation of our study. By inserting congruency level predictions as a second task into the normal Stroop procedure, we might have introduced a procedural change that hampered a comparison with typical Stroop performance. Admittedly, it is not clear to what extent we can generalize our findings to "normal" Stroop or congruency tasks. Further research will be needed to verify whether participants actively generate predictions when they are not explicitly asked ti. Irrespective of this, our findings demonstrate an impact of expectancies on sequential modulations of congruency effects, and this finding makes a strong case for the cognitive malleability of the processes underlying transient conflict adaptation. Consequently, we propose that proactive control processes in general, and repetition expectancy in particular, should be given more attention in current theorizing and modelling of cognitive control, which is characterized by an emphasis on reactive, conflict-induced control adjustments.

ACKNOWLEDGMENTS

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CHAPTER 4
WHEN PREDICTIONS TAKE CONTROL: THE EFFECT OF TASK PREDICTIONS ON TASK SWITCHING PERFORMANCE[1]

In this paper, we aimed to investigate the role of self-generated predictions in the flexible control of behaviour. Therefore, we ran a task switching experiment in which participants were asked to try to predict the upcoming task in three conditions varying in switch rate (30%, 50% and 70%). Irrespective of their predictions, the colour of the target indicated which task participants had to perform. In line with previous studies (Mayr, 2006; Monsell & Mizon, 2006), the switch cost was attenuated as the switch rate increased. Importantly, a clear task repetition bias was found in all conditions, yet the task repetition prediction rate dropped from 78% over 66% to 49% with increasing switch probability in the three conditions. Irrespective of condition, the switch cost was strongly reduced in anticipation of a task alternation compared to the cost of an unexpected task alternation following repetition predictions. Hence, our data suggest that the reduction in the switch cost with increasing switch probability is caused by a diminished expectancy for the task to repeat. Taken together, this paper highlights the importance of predictions in the flexible control of behaviour, and suggests a crucial role for task repetition expectancy in the context-sensitive adjusting of task switching performance.

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[1] This chapter is based on: Duthoo, W., De Baene, W., Wühr, P., & Notebaert, W. (2012). When predictions take control: The effect of task predictions on task switching performance. *Frontiers in Cognition, 3*.

INTRODUCTION

A hallmark of human cognition lies in the ability to proactively anticipate relevant future events and steer both action and perception accordingly. Current influential theories of cognition advance this proactive prediction generation ability as a central mechanism of brain functioning, marking a shift away from the view of the brain passively reacting to incoming stimulation. Predictive representations of both visual (e.g., Bar, 2007; Summerfield & Egner, 2009), auditory (Kumar et al., 2011) and olfactory (Zelano, Mohanty, & Gottfried, 2011) information have been shown to guide and prepare the brain for a forthcoming stimulus, aiding information processing in a noisy and unpredictable environment. By continuously generating predictions about the environment, the cognitive system is also able to learn and associate specific actions or stimuli with specific outcomes. Learning on the basis of these prediction-driven outcomes is ascribed a central role in optimizing action selection and response execution in recent modelling work (Alexander & Brown, 2011; Silvetti, Seurinck, & Verguts, 2011). In line with the conception of the predictive brain, this paper aimed to investigate how self-generated predictions can flexibly steer attentional control through advance preparation, by referring to recent empirical work in the Stroop conflict task (Duthoo, Wühr, & Notebaert, 2013) and providing new evidence from a task switching experiment.

Attentional control is typically studied by means of a conflict paradigm, such as the Stroop conflict task (see MacLeod, 1991, for a review). In this task, participants are asked to respond to the colour of a colour word while ignoring its meaning. As the colour and word dimension of the stimulus can either overlap or not, easy (congruent) and difficult (incongruent) stimulus conditions are created, respectively. Optimal task performance requires adaptively adjusting attention to the relevant (colour) and irrelevant (word meaning) dimension. In general, these attentional adjustments can be grouped into two categories based on the underlying mechanism and the moment in time they are implemented by the cognitive system (Wühr & Kunde, 2008; Egner, 2007). According to a *reactive* control account, adjustments to the control settings occur in response to the target, corresponding to the metaphor of the reactive brain. Current models typically assume that it is the conflict on a given trial that triggers subsequent control up-regulation, characterized by a strengthening of task-relevant associations (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Verguts & Notebaert, 2008; 2009). This theoretical framework has been successfully applied to many attentional control phenomena, including the reduction of the congruency effect following high-conflict incongruent trials in single-task paradigms (i.e., the congruency sequence effect (CSE); Gratton, Coles, & Donchin, 1992; for a review, see Egner, 2007), but also the increase of the switch cost following high-conflict incongruent stimuli in dual-task paradigms (e.g., Goschke, 2000; Braem, Roggeman, Verguts, & Notebaert, 2012). Alternatively, control adjustments can also be triggered in anticipation of the upcoming task or target, biasing the task or attentional set proactively. These *proactive* control adjustments, captured by the metaphor of the predictive brain described above, have received considerably less attention in the cognitive control literature.

In order to investigate this type of expectancy-induced control, two different strategies have been pursued. On the one hand, participants' expectancies can be manipulated implicitly. Studies on attentional control have, for example, manipulated the proportion of incongruent trials (Logan & Zbrodoff, 1979) or congruency level transitions (Duthoo & Notebaert, 2012) to induce preparatory strategic control adjustments. Whereas the first manipulation successfully triggered anticipatory control, reflected in faster reactions to highly expected incongruent trials than to unexpected congruent trials, the second, more subtle manipulation appeared not strong enough to elicit expectancy-induced adaptation effects that were clearly dissociable from reactive, conflict-induced adjustments (see also Jiménez & Méndez, 2013). Alternatively, a more common and widespread experimental tool to probe anticipatory control adjustments is to cue participants explicitly about the upcoming stimulus event (for some early experimental work with the cueing paradigm, see Harvey, 1984; Neill, 1978; Logan & Zbrodoff, 1982). More recently, Aarts and Roelofs (2011) applied a probabilistic cueing procedure to a Stroop-like task to point out that the anticipation of upcoming conflict (or lack of conflict) can trigger similar sequential adjustments as experienced conflict (or lack thereof) on the previous trial, both behaviourally and in the activation pattern of the anterior cingulate cortex (ACC). In similar vein, Correa, Rao, and Nobre (2009) found that anticipating conflict in a cued congruency task sped up both conflict detection and conflict resolution.

However, investigating proactive control by means of a cueing paradigm is not really testing the implications of a predictive brain, as it is assumed that we constantly generate predictions ourselves. Compared to the large amount of studies concerning cue-induced attentional control, few studies have centred on the effect of self-generated predictions on subsequent processing. Yet, human predictive behaviour itself has been the focus of much experimental work outside the field of cognitive control. Interestingly, an influential line of research revealed that people's predictions and expectancies are often strongly biased (e.g., Kahneman, Slovic, & Tversky, 1982), as they either overestimate or underestimate the actual probability of events to occur (see also Ayton & Fischer, 2004). When confronted with a random run of stimuli, participants will typically indicate that longer runs of a particular event have to be balanced out by the occurrence of the alternative event, a phenomenon known as the gambler's fallacy. This tendency for negative recency is also typically found when people are asked to generate or identify a random sequence (see Nickerson, 2002, for a review). However, other studies have shown that people can also display the opposite expectancy bias, the tendency to predict positive recency. A study of Kareev (1995), for example, in which participants were asked to predict the next item on the list, revealed that subjects typically overestimate repeating events. According to Kareev, this repetition bias stems from a persistent tendency to perceive or find patterns and causality in the environment (note, however, that the same tendency, seen from another perspective, can also result in probability matching behaviour at the outcome level, the strategy to predict the events in proportion to their probability of occurrence; see Gaissmaier & Schooler, 2008). Apart from its impact on simple serial 2-choice reaction time tasks (Remington, 1969; Soetens, Boer, & Hueting, 1985), the impact of this expectancy bias on information processing and attentional control remains still relatively uninvestigated. Given both these persistent prediction biases and the cognitive system's inherent prepotency to generate predictions and evaluate its outcomes, investigating self-generated expectancies and comparing their impact on subsequent processing to that of exogenously triggered expectancies might reveal new insights into how the brain implements proactive control.

In a previous study (Duthoo et al., 2013), we undertook a first attempt to measure these biased predictions explicitly and verify their influence on cognitive control by subjecting participants to a Stroop task and letting them predict the congruency level of the upcoming Stroop stimulus. Interestingly, after recoding participants' predictions ('Do you expect a congruent or incongruent trial?') relative to the congruency level of the previous trial, results revealed a clear repetition bias in the prediction pattern: in line with Kareev (1995), participants expected the congruency level to repeat from one trial to the next in 65% of all cases, even though congruency level repetition probability was set at 50%. Moreover, attentional adjustments (i.e., a CSE) were only found when they anticipated a congruency level repetition. Participants showed both a reduced interference of repeating conflict trials (by proactively narrowing attention to the stimulus colour) and increased facilitation of repeating non-conflicting trials (by proactively allowing the word meaning to influence response selection). In case of an unexpected congruency level alternation, these preparatory adjustments backfired and longer reaction times were registered, resembling the results of Aarts and Roelofs (2011) in a probabilistic cueing experiment. Interestingly, analyses of the congruency alternation predictions also suggested that in anticipation of an alternation, participants seemed to switch to a default control mode, as no sequential adjustments were found. In sum, the study revealed a clear bias towards predicting repeating events, and an optimization of control processes (i.e., a CSE) in anticipation of such repeating events.

Contrary to the literature on conflict control, the contribution of a preparatory component in task switching research has played a central role in the theoretical debate (e.g., see Karayanidis et al., 2010 and Kiesel et al., 2010 for recent overviews), overshadowing research on the reactive priming effects of the previous task set on current task performance. In order to investigate these proactive adjustments, similar strategies have been implemented, aimed at inducing expectancies either implicitly or explicitly. As an example of the former strategy, fixed (predictable) task sequences (i.e., the alternating-runs paradigm; Rogers & Monsell, 1995) have been introduced to compare predictable task switch trials to predictable repetition trials. Even though two simple tasks were used and the task sequence was entirely predictable, this paradigm consistently evoked increased reaction times and higher error rates on switch compared to repetition trials (i.e., robust switch costs). To probe the impact of explicit expectancies on these switch costs, the explicit cueing paradigm (Meiran, 1996) was developed, in which cues specified the required task in a random run of task repetitions and switches. This cueing paradigm has been extensively used to evidence preparatory reductions in switch costs (e.g., Meiran, 1996; Koch, 2003), albeit not without its own set of methodological pitfalls (see Logan and Bundesen, 2003; but see also De Baene & Brass, 2011 and Jost, De Baene, Koch, & Brass, 2013).

Research on task switching has convincingly shown how increasing the preparation interval prior to an anticipated task alternation led to more controlled processing (i.e., a reduced switch cost). Monsell, Sumner, and Waters (2003), for example, reported performance benefits for predictable compared to unpredictable task switches, suggesting that participants can strategically control their task-set readiness in function of their expectation, and, more precisely, in function of the probability of encountering a task-switch on the upcoming trial. In similar vein, further research has robustly found a reduced switch cost with increasing switch probability (Bonnin, Gaonac'h, & Bouquet, 2011; Mayr, 2006; Monsell & Mizon, 2006; Schneider & Logan, 2006). Others have pointed out that not only when expecting a task alternation, but also in anticipation of an expected task repetition, task-set readiness can be adjusted for optimal task performance, resulting in strong repetition benefits (Dreisbach, Haider, & Kluwe, 2002). In sum, more so than in single-task paradigms, dual-task performance seems to rely on a strong anticipatory control component.

Even though the theoretical debate about this anticipatory control component is still ongoing, a key role is usually attributed to repetition expectancy. For example, the smaller difference between switch and repeat trials in a context with a 50% compared to a 30% switch probability is sometimes explained by the fact that participants match their task preparation to the probability of the switch and repeat conditions, thus equally preparing both tasks in a 50% switch probability context (Dreisbach et al., 2002; Brass & von Cramon, 2004; Monsell & Mizon, 2006). Alternatively, other authors suggested that people prepare the other task on part of the trials (e.g., Monsell & Mizon, 2006), resulting in extra preparation and thus longer reaction times on task repetition trials (when their guess was wrong) and less preparation and thus faster reactions to task switch trials (when their guess was right). Importantly, both explanations stress the importance of expectancies about the upcoming task. However, as indicated above, past research has consistently found that people's predictions are biased and therefore often do not match the actual probability in a given context (especially in the context of a random sequence of events; but see the work of Gaissmaier and Schooler, 2008, showing that the search for patterns can also result in probability matching at the outcome level). Moreover, the abovementioned studies never measured expectancies themselves, so that it remains a question for further research how expectancies can steer task preparation.

To shed some light on this issue, as well as to compare self-generated predictions in a dual-task paradigm to previous findings in a single-task paradigm, we decided to apply a similar procedure as our previous study on prediction-driven adjustments in the Stroop task (Duthoo et al., 2013). Therefore, we asked participants to try to predict the upcoming task on a trial-by-trial basis in one of three between-subjects conditions varying in switch rate (30%, 50% and 70%), and probed both how these contexts affected the prediction pattern and how these predictions themselves influenced the task switch cost. Similar to our previous findings in the Stroop task, we expected predictions to evoke advance preparation for the upcoming target. More specifically, we expected repetition predictions to induce a strong reaction time benefit when a task repetition was actually presented, and a huge cost when one had to unexpectedly switch tasks, irrespective of condition. In contrast with the strong switch costs (and repetition benefits) following repetition predictions, we expected that alternation predictions evoke less strong preparatory effects (Duthoo et al., submitted), thereby reducing the switch cost, irrespective of condition. Consequently, assuming that participants' tendency to predict task repetitions is attenuated with increasing switch probability, we predicted to replicate the finding of a reduced switch cost in contexts of higher switch probabilities (Mayr, 2006; Monsell & Mizon, 2006; Schneider & Logan, 2006).

METHOD

PARTICIPANTS

A group of 48 Ghent University students (30 females; 14 males; ages 17-28 years) signed up to participate in one of the three conditions ($n = 16$) of the experiment, lasting approximately 45 minutes. They received a monetary payment in return. Prior to the testing, participants provided written informed consent.

STIMULI AND APPARATUS

A program written with T-scope software (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 2006) controlled the experiment. All stimuli were displayed on a 17-inch monitor, with a viewing distance of approximately 50 centimetres. The numbers 1 to 9, with the exclusion of 5, served as the target stimuli, presented in Arial, font size 32. These stimuli were presented centrally on a black background in yellow (for the magnitude task) or blue (for the parity task). Responses were registered by means of a QWERTY keyboard.

DESIGN AND PROCEDURE

Participants were randomly assigned to one of the three experimental conditions, differing only in the amount of task switches during the three blocks where an explicit task prediction was registered. In the *repetition condition*, the task switch probability was restricted to 30%. In the *intermediate condition*, participants were confronted with an equal amount of task repetitions and alternations (50%). The *alternation condition* increased the task switch probability to 70%.

Throughout all blocks of the experiment, each target number was equally often presented in blue and yellow, implying that within each block participants performed an equal amount of magnitude and parity judgements. Selection of the target number was pseudo-random, with the restriction that each of the eight possible number targets appeared an equal amount of times in each of the two possible colours within one block. In all dual-task blocks, consisting of 80 trials, each target number was thus presented five times in both blue and yellow. Participants had to respond by pressing the E or U keyboard key for small or even target numbers and the R or I keyboard key for large or odd target numbers. The mapping of the task (magnitude or parity) to the middle and index finger of the left hand (keys E and R, respectively) or index and middle finger of the right hand (keys U and I, respectively) was counterbalanced across participants. In order to indicate which of the two tasks they expected, participants had to press the V or N key with their thumbs. The mapping of these keys to either a magnitude or parity task prediction was compatible with the mapping of the left or right hand to one of the two tasks.

In all conditions, participants were first trained on each of the two tasks separately during 40 trials of first magnitude and then parity judgements, adding up to 80 single task practice trials. Hereafter, the two tasks where combined during two blocks of 80 trials, as to familiarize participants with the dual task procedure. For these dual task training blocks the task switch probability was kept at 50% in all three conditions. The colour in which targets were presented indicated the task participants had to perform. A yellow number target asked for a magnitude judgement, whereas a blue target required a parity response. In the final phase of the experiment, three blocks of 80 trials were presented during which participants first had to predict which of the two tasks they expected to come next. Irrespective of their choices, the colour in which the upcoming target was presented again indicated which of the two task participants had to perform, thereby serving as a feedback signal for their task predictions. For their performance on the target numbers no error feedback was provided. A store coupon was promised to the participant who performed best in the three last blocks for each condition, taking into account both the amount of correct predictions and mean reaction times and error percentages. In between blocks, participants took a short, self-paced break. After completing the experiment, participants filled in a short questionnaire, probing their awareness of the switch probability manipulation and their use of strategies in predicting the task sequence.

Each trial started with the presentation of a fixation cross for 500 milliseconds. In the training blocks, this was followed by the target, which appeared on the screen until a response was registered, with the maximal reaction time restricted to 2500 milliseconds. Next, the screen turned black for 500 milliseconds, serving as the inter-trial-interval. In trials in which participants also had to predict the task on the next trial, a fixation cross was first presented for 500 milliseconds, after which an instruction appeared on the screen (‘Next trial?’) that remained visible on the screen until participants clicked one of the two designated keyboard keys. Hereafter, a fixation cross was again displayed for 500 milliseconds, after which a number target appeared on the screen, with identical timing values as described above.

RESULTS

In the results section, we focus on the three experimental blocks in which predictions were also registered. Two participants who did not engage in the prediction task (by ‘predicting’ the same task throughout at least one of the three experimental blocks) were removed from the analysis, restricting the number of participants in the intermediate and alternation condition to 15. Non-responses and badly recorded data (adding up to 1.6%) were excluded from both the reaction time and performance error analysis. We applied the multiple comparison correction method put forward by Holm (1979) in order to control for the family-wise error rate, adjusting the *p*-values of the post tests in the reaction time and error analysis accordingly.

DATA CLEANING

Before conducting the reaction time analysis, the data were subjected to a trimming procedure. We first excluded the trials on which participants committed an error (8.1% of the remaining data; distributed equally over the three conditions). Hereafter, the first trial of each block and RT outliers (± 2.5 *SD*, calculated separately per condition, subject and task) were removed (another 3.9%). Taken together, the analysis was thus carried out on 86.9% of the complete data.

REACTION TIMES AND PREDICTIONS

First, a mixed-design analysis of variance with the between-subjects variable Condition (three levels: repetition, intermediate and alternation) and the within-subjects variables Task (two levels: magnitude and parity) and Sequence (two levels: repetition and alternation) was carried out. Results revealed main effects of Task, $F(1, 43) = 57.36$, $p < .0001$, reflecting faster magnitude than parity judgments (757 and 877 ms, respectively) and Sequence, $F(1, 43) = 116.95$, $p < .0001$, indicating the presence of a switch cost of 106 ms, but not a main effect of Condition, $F(2, 43) < 1$, *ns*. The two-way interaction between Task and Sequence turned out significant as well, $F(1, 43) = 5.47$, $p < .05$, reflecting a larger switch cost for the parity task compared to the magnitude task (120 and 93 ms, respectively), irrespective of Condition, $F(2, 43) < 1$, *ns*. Most importantly, the analysis revealed a two-way interaction between Sequence and Condition, $F(2, 43) = 11.05$, $p < .0001$, implying that the size of the switch cost was significantly affected by the transitional manipulation. Further independent-samples *t*-tests showed that, compared to the switch cost of 112 ms in the intermediate condition, the switch cost was significantly reduced to 52 ms by increasing the switch probability in the alternation condition, $t(28) = 3.5$, $p < .01$. Decreasing the switch probability to 30% in the repetition condition significantly increased the switch cost to 166 ms compared to the alternation condition, $t(29) = 4.5$, $p < .0001$. The increase in switch cost of 54 ms in the repetition compared to the intermediate condition was only marginally significant, $t(29) = 2.0$, $p = .056$. These differences in the switch cost over conditions are depicted in Figure 1.

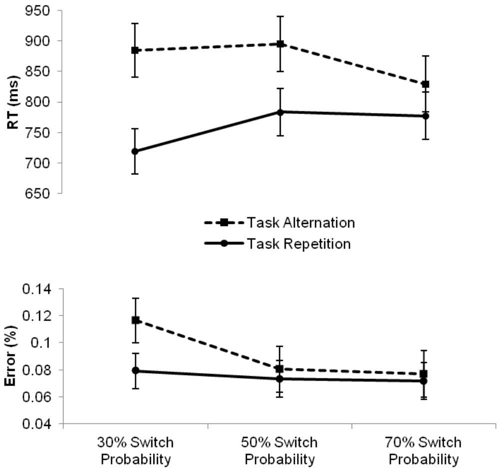

Figure 1: Mean reaction times (RTs, in milliseconds) and error percentages for task alternations (dashed line) and task repetitions (full line) in the three conditions varying in switch probability. Error bars represent 95% confidence intervals around the mean.

Next, we took a deeper look into participants' task prediction patterns. Irrespective of condition, participants predicted the magnitude and parity task equally often (i.e., 50%, on average, *SD* = 5.4%). These task predictions were then recoded into repetition or alternation predictions, relative to the task presented on the previous trial. In line with our manipulation of task switch probability, participants in the repetition condition predicted more task repetitions (78%), both compared to participants in the intermediate (66%, independent-samples *t*(29) = 3.1, *p* < .001) and participants in the alternation condition (51%, independent-samples *t*(29) = 7.63, *p* < .0001). Remarkably, in all three conditions a task repetition bias was found, as comparisons between the task switch prediction rate and the actual task switch probability indicated that both in the intermediate condition (66% compared to 50%, *t*(14) = 6.77, *p* < .0001), repetition condition (78% compared to 70%, *t*(15) = 2.86, *p* < .05) and alternation condition (51% compared to 30%, *t*(14) = 8.39, *p* < .0001) the amount of task repetitions was consistently overpredicted.

Finally, we examined the effect of these task predictions on task performance, by investigating how repetition and alternation expectations impacted the switch cost. To this end, we ran a mixed-design analysis of variance with the between-subject variable Condition (three levels: repetition, intermediate and alternation) and the within-subjects variables Prediction and Sequence (two levels: repetition and alternation)[2]. Apart from the main effect of Sequence, $F(1, 43) = 59.89$, $p < .0001$, reflecting a switch cost, the analysis also revealed a marginally significant main effect of Prediction, $F(1, 43) = 3.87$, $p = .056$, indicating that number targets were responded to 17 ms slower following alternation predictions than following repetition predictions. Importantly, a significant interaction between Prediction and Sequence was also found, $F(1, 43) = 88.75$, $p < .0001$. The three-way interaction with Condition did not reach significance, $F(2, 43) < 1$, *ns*, suggesting that participants' predictions influenced the switch cost similarly in all three conditions. Following an alternation prediction, the switch cost, calculated as the difference between an expected task alternation and an unexpected task repetition, disappeared completely. Even though inspection of the reaction times suggested a switch benefit numerically (24, 31 and 32 ms in the repetition, intermediate and alternation condition, respectively), post tests indicated that this difference did not reach statistical significance in any of the conditions (all *p*s > .62). Following a repetition prediction, a huge and significant repetition benefit, calculated as the difference between an unexpected task alternation and an expected task repetition, was found in all conditions (222, 116 and 147 ms in the

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[2] We did not include the variable Task in this analysis, as this would cause some of the cells of the ANOVA to be calculated on a very limited amount of observations (for instance: a switch to the parity task following an alternation prediction in the repetition condition). We therefore collapsed observations over the two tasks. Still, running the analysis with the Task variable included did not change the pattern of the results. Importantly, the Task variable did not interact significantly with any of the other variables (all *p*s > .14).

repetition, intermediate and alternation condition, respectively; all *p*s < .0001). This pattern of reaction times is visualized in Figure 2.

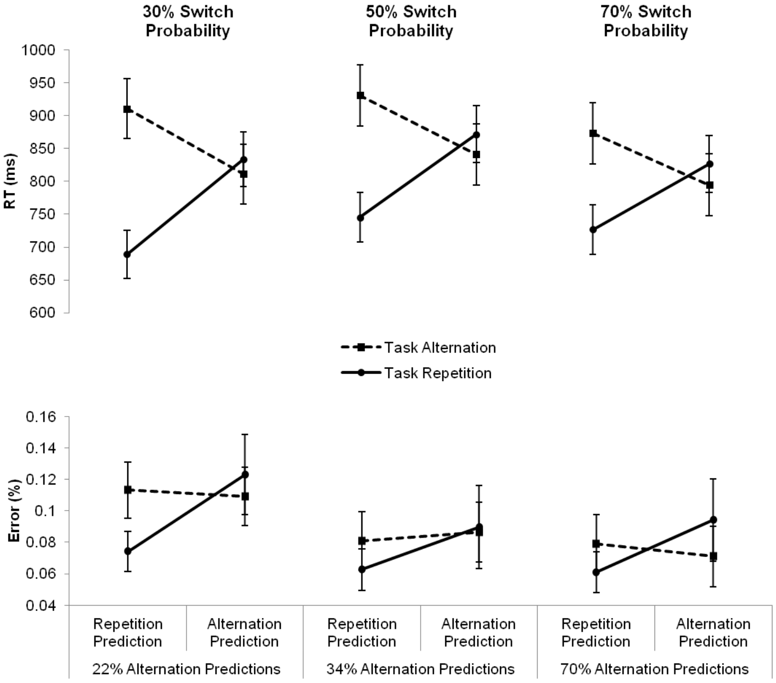

Figure 2: Mean reaction times (RTs, in milliseconds) and error percentages for task alternations (dashed line) and task repetitions (full line) following repetition and alternation predictions, separately for the three conditions varying in switch probability. Under each of the graphs, the corresponding overall percentage of alternation predictions is presented. Error bars represent 95% confidence intervals around the mean.

ERROR PERCENTAGES

First, we ran a mixed-design ANOVA with the between-subjects variable Condition (three levels: repetition, intermediate and alternation) and the within-subjects variables Task (two levels: magnitude and parity) and

Sequence (two levels: repetition and alternation) on the aggregated error scores. Similarly to the reaction time analysis, we found main effects of Task, *F*(1, 43) = 36.61, *p* < .0001, reflecting worse performance on parity than magnitude judgments (12% and 4.6%, respectively) and Sequence, *F*(1, 43) = 9.51, *p* < .01, indicating higher error rates on task alternations than on task repetitions (9.2% and 7.4%, respectively), but no main effect of Condition, *F*(2, 43) < 1, *ns*. The two-way interaction between Task and Sequence also reached significance, *F*(1, 43) = 5.07, *p* < .05, indicating that switching to a parity task (compared to repeating this task) increased the error rate (3.2%), whereas switching to a magnitude task did not. Most importantly, we again found a significant interaction between Sequence and Condition, *F*(2, 43) = 3.22, *p* < .05, indicating that the size of the error switch cost differed significantly between the three conditions, irrespective of task, *F*(2, 43) < 1, *ns*. Further independent-samples *t*-tests revealed that this interaction was brought about by a significant increase in the error switch cost (3.7%) in the repetition condition compared to the intermediate condition, *t*(29) = 2.09, *p* < .05, whereas the error switch cost was not statistically lower in the alternation condition compared to the intermediate condition, *t*(28) < 1, *ns*. The error rates for task repetitions and task alternations in each of the three conditions are visualized in Figure 1.

In order to investigate how participants' predictions had an impact on the error rates, we conducted another repeated-measures ANOVA with the between-subjects variable Condition (three levels: intermediate, repetition and alternation) and the within-subjects variables Prediction and Sequence (two levels: repetition and alternation). This analysis revealed only a main effect of Prediction, *F*(1, 43) = 5.73, *p* < .05, indicating that an alternation prediction produced more erroneous responses compared to a repetition prediction (9.6% and 7.8%, respectively). The two-way interaction between Prediction and Sequence was only marginally significant, *F*(1, 43) = 3.3, *p* = .076. The data pattern closely resembled the reaction pattern, showing a trend for the error switch cost to be absent following alternation predictions, and present following repetition predictions. Again, this pattern did not differ significantly between the three conditions, $F(2, 43) < 1$, *ns*. The error rates for task repetitions and task alternations following repetition and alternation predictions in each of the three conditions are presented in Figure 2.

GENERAL DISCUSSION

In the present study, we aimed to investigate how self-generated predictions influence conflict and task control, expanding previous research on expectancy-induced proactive control. To do so, we inserted explicit task predictions into a task switching procedure, thereby complementing as well as elaborating on a previous experiment in which the influence of congruency level predictions on subsequent Stroop performance was put to the test (Duthoo et al., 2013). Results revealed three interesting findings.

Firstly, analysis of participants' prediction patterns exposed a bias towards predicting task repetitions in all three conditions. In the intermediate condition, in which the two tasks alternated in 50% of all transitions, participants displayed a clear task repetition bias (66%). Also in the alternation condition, participants still predicted a task repetition in 51% of all transitions, when only 30% were actually presented. Moreover, reaction times and error rates showed that irrespective of condition, reactions following a task alternation prediction were slower. At first sight, this tendency to predict repeating stimulus events, or 'hot hand fallacy', might seem at odds with the literature on probability matching (Gaissmaier & Schooler, 2008), revealing participants' tendency to match their choice behaviour to the actual probability of two stimuli that are not equally likely to be presented. Yet, given that participants in the current experiment were asked to predict the upcoming task rather than the task transition, participants matched probabilities quite well, as irrespective of condition the two tasks were predicted equally often (i.e., 50%). Still, further insight into the transitional probabilities could help them predicting the upcoming task more accurately. Yet, these transitional probabilities were less readily picked up, since the experiment revealed a clear bias towards expecting repetitions. Interestingly, participants’ prediction error rate only dropped from 50% to 38% in the repetition condition ($t(15) = 8.9$, $p < .0001$), in which transitional probability was in line with their repetition expectancy bias.

Secondly, our manipulation of switch probability affected the switch cost as predicted: compared to the switch cost in the intermediate condition with a 50% switch probability, increasing this switch probability decreased the switch cost significantly, whereas decreasing the switch probability strongly amplified the switch cost. Put differently, the switch cost is attenuated under conditions of high switch probability, replicating previous studies (Bonnin et al., 2011; Mayr, 2006; Monsell & Mizon, 2006; Schneider & Logan, 2006). Moreover, results also revealed that switching to the parity task came at a greater cost than switching to the magnitude task, both in reaction time and accuracy. This corresponds well with previous research on asymmetries in switch costs showing that separating the response set of the two tasks results in greater costs in switching to the more difficult task (Yeung & Monsell, 2003). In the current experiment, response set overlap was reduced in terms of response decisions (parity versus magnitude judgments) and stimulus-response mapping (both tasks were mapped to separate hands). Most importantly, this task asymmetry did not interact with predictions, which formed the main focus of this study.

Thirdly, by inserting explicit predictions into the dual task procedure, we were able to identify a potential mechanism underlying the finding of reduced switch costs in conditions with high switch probability. In all three conditions, the same prediction-driven behavioural adjustments were found: following an alternation prediction, the difference between repetition and switch trials disappeared, whereas repetition predictions were followed by a large switch cost (or a large repetition benefit). Participants in the alternation condition expected more alternations, thereby reducing the switch cost significantly. In other words, the reduction in switch cost in a context of high switch probability might stem from proactively switching to a more controlled processing strategy when expecting task alternations. However, preparing for a task alternation still comes at a cost, as comparisons between correctly predicted task repetitions and alternations revealed a significant residual task switch cost (all *p*s < .001). This finding is in line with studies using the explicit cueing paradigm that consistently show that even validly cued task alternations robustly slowed down responses compared to validly cued task repetitions (Meiran, 1996).

On an important note, part of the speed-up in reaction time following correct predictions might reflect an effect of hand priming, as in the current design correct predictions involved the finger of the same hand needed for subsequent task execution, whereas incorrect predictions entailed a switch of hand (e.g., Cooper & Marí-Beffa, 2008). Still, this definitely cannot account for the whole pattern of findings, since predicting the other task relative to the task on the previous trials correctly (i.e., a task alternation in which the same hand was used for predicting and responding to the target) did not produce reactions that were significantly faster than following incorrect task alternation predictions, in which the task repeated but the hand used for predictions differed from the hand used for responding to the target. Taken together, this study suggests that in a dual-task environment, participants expect the task to repeat, leading to improved performance when it does and a large cost when it alternates. Still, in anticipation of a task alternation, participants respond equally fast to a task alternation as to a task repetition. These conclusions are clearly in line with a proactive, expectancy-based account of task switching.

Moreover, the current findings allow drawing interesting parallels between this experiment and the aforementioned previous Stroop experiment, both in the patterns of self-generated expectancies as in their effect on subsequent processing. Compellingly, we found a robust bias towards overpredicting repeating events that was also present in congruency level predictions in the Stroop task. This bias towards expecting task repetitions coincided with a clear processing benefit for these repetition predictions, as alternation predictions typically induced higher errors rates and increased reaction times, irrespective of condition. Interestingly, the observation of reaction time benefits following repetition expectations but not after alternation expectations also bears a striking resemblance to findings within the voluntary task switching paradigm (Arrington & Logan, 2004). In this paradigm, participants can choose which task to perform on a series of bivalent stimuli, with the instruction to perform both tasks equally often. In line with the inherent bias towards repetitions defended in this paper, Arrington and Logan found that the subjects produced more task repetitions (i.e., 68%) than expected if the tasks were performed in a pure random sequence. Moreover, deliberately choosing to switch tasks slowed down task performance significantly (i.e., a significant *switch cost* was found). Taken together, the experiment revealed that participants displayed a clear reluctance to switch tasks.

Similar to the voluntary task repetition and switch decisions, repetition and alternation predictions clearly produced a differential effect on subsequent processing: repetition predictions were followed by a strong reaction time benefit when an actual task repetition was presented, and a large cost when one then had to (unexpectedly) switch. Again, this pattern closely resembled findings in our previous Stroop study (Duthoo et al., 2013), where a clear congruency level repetition benefit and congruency level alternation cost were found following repetition predictions. Yet, whereas congruency level alternation predictions were, on first sight, not followed by behavioural adaptations in the Stroop task (or cancelled out by reactive control adjustments evoked by conflict on the preceding trial), the current experiment showed that following task alternation predictions the difference between an actually presented task alternation and an unexpected task repetition disappeared.

Crucially, this pattern of results did not differ between the three conditions varying in switch probability. Therefore, the present experiment suggests an explanation for the often replicated finding of reduced switch costs in conditions with a higher switch probability (Monsell & Mizon, 2006; Mayr, 2006; Schneider & Logan, 2006): increasing the switch probability increases the expectancy for task alternations, which was found to be followed by a reduction in the switch cost. However, the interpretation of this reduced switch cost in anticipation of a task alternation is still open to debate.

One possible explanation, as was also put forward by Monsell and Mizon (2006), is that participants adopt a ‘neutral control state’, right in between the two task sets. When the colour of the target then indicated which of the two task sets was appropriate, reactions to either one of the two tasks would be equally fast. This is exactly the pattern of results we found following alternation predictions, and it emerged in all three conditions. Moreover, this corresponds well with the absence of sequential modulations of the Stroop effect following congruency level alternation predictions, which can also explained by participants adopting a ‘neutral control mode’ (Duthoo et al., 2013).

Alternatively, one can assume that both repetition and alternation predictions lead to advance preparation of the upcoming task, yet preparation for task alternations is never complete (i.e., there is a residual switch cost, e.g., Meiran, Chorev, & Sapir, 2000). Also in our experiment, correctly predicted task alternations were responded to much slower than correctly predicted task repetitions, irrespective of condition. In case of a correctly predicted task alternation, advance preparation speeds up responding compared to an unexpected task alternation (i.e., following a task repetition prediction). Yet, because of a residual switch cost, these reactions are not significantly faster than those to unexpected task repetitions (i.e., following a task alternation prediction), where preparation misfires, but no residual switch cost affects performance. The same logic holds if one assumes the difference between switch and repeat trials to arise from adaptation to the task set on repetition trials, reflected in a repetition benefit, rather than from reconfiguration of the task set on switch trials, reflected in a (residual) switch cost (De Baene, Kühn, & Brass, 2012). In the case of an unexpected task repetition following a task alternation prediction, reaction times will be relatively slower than for expected task repetitions, yet equally fast to an expected task alternation, where no task-set adaptation benefit was present.

However, the current data do not allow differentiating between the adaptation and reconfiguration view, as both predict the same data pattern: following correct repetition predictions, both preparation and task set adaptation (or lack of reconfiguration) will speed up an actual task repetition, whereas following correct alternation predictions, preparation and the lack of task-set adaptation (or need for reconfiguration) have effects in opposite directions, explaining the intermediate reaction times. Whether this explanation in terms of equal preparation for switch and repeat trials following both types of predictions is to be favoured over an explanation in terms of a lack of specific preparation for alternation predictions (i.e., a neutral control mode) is an interesting question for future research.

Yet, the current experiment applied a 1:1 mapping between the cue (i.e., the colour of the target) and the task (i.e., a magnitude or parity judgment), so that task repetitions were confounded with repetitions of the cue. Therefore, this design does not allow teasing apart the facilitatory effect of repeated-cue-encoding in task repetitions from the effect of executive control processes reconfiguring the cognitive system in task alternations. In order to disentangle cue repetitions from task repetitions, some previous studies have introduced multiple cues per task (e.g., Logan & Bundesen, 2003; Mayer & Kliegl, 2003; see Schneider & Logan, 2011, for a comparison between 1:1 and 2:1 cue-to-task mappings). This approach has led to a rich body of empirical evidence showing that repetition priming of cue encoding is indeed an important component of task switching. Note, however, that these studies have also demonstrated that there are usually also substantial ‘true’ task switch costs remaining (for a review of this evidence, see Jost et al., 2013).

Important in the light of the current results is a study of Schneider and Logan (2006), in which this 2:1 cue-to-task mapping was combined with a transitional probability manipulation similar to ours. In line with the current findings, switch costs were smallest in the condition with a high switch probability and largest when the amount of task repetitions was increased. Modelling of their data led these authors to conclude that the difference in the switch costs between different frequency conditions reflected (automatic or strategic) priming of cue encoding for the frequent transitions. Therefore, an interesting avenue for future research lies in combining a 2:1 mapping strategy with our prediction manipulation to elucidate whether the prediction-driven adjustments in task switching performance reported in this paper were driven by facilitating the speed of cue encoding rather than by promoting advance configuration of task-set.

Given the emphasis recent theories place on prediction-driven adjustments in brain functioning, the paradigm to assess self-generated predictions and probe their impact presented in the current article seems a particularly promising tool for further research. Applying this method, we were able to pinpoint structural biases in human predictions and measure their influence on subsequent processing in a direct way, rather than inferring explanations in terms of expectancy indirectly from the data. Yet, one outstanding question remains whether participants will make similar predictions when they are not explicitly asked to generate them, and, consequently, to what extent these expectancy-driven attentional adjustments can also be found in ‘normal’ Stroop or dual-task behaviour.

In conclusion, the research presented in this paper advocated viewing the brain as a predictive rather than a purely reactive device. In this light, the overestimation of repeating events (also referred to as ‘the hot hand fallacy’) should not necessarily be considered as a weakness of our predictive brain. In real life, there is a much stronger correlation between sequential events than in our artificial lab tasks. For instance, when the road is slippery because of wet conditions in one turn, it is usually a good idea to predict that also the next turn will be slippery and adjust accordingly. It therefore appears adaptive that the cognitive system is more readily optimized in anticipation of a repeating event. This is reflected in a strong repetition benefit for both congruency level and task repetitions. Yet, when interpreting the lack of conflict adaptation and the reduced difference between task repetition and alternations following alternation predictions in terms of participants adopting a neutral control mode, it remains an extremely interesting question to what extent our brain can also prepare for expected changes.

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CHAPTER 5

ERP CORRELATES OF PROACTIVE AND REACTIVE CONTROL IN THE STROOP TASK[1]

In the present study, we aimed to investigate the neural correlates of proactive and reactive control by recording the EEG in a vocal Stroop task. Before responding to the Stroop stimulus, participants were asked to predict the upcoming congruency level, as to elicit proactive adjustments. Replicating previous work (Duthoo, Wühr, & Notebaert, 2013), behavioural results revealed that participants were biased to expect repetitions of the congruency level over successive trials and that sequential adjustments in Stroop performance (e.g., a congruency sequence effect) were only evident following these repetition predictions – and absent with alternation predictions. To better understand this pattern, we investigated the influence of conflict on the previous trial and prediction type on known EEG markers of Stroop performance. Analysis of the N450 component revealed an influence of predictions on reactive control adjustments: For alternation predictions, the N450 on congruent trials following an incongruent trial was significantly reduced. The conflict slow potential, on the other hand, was not modified by predictions, yet showed to be sensitive only to the congruency level of the previous trial. We also compared the CNV to look for differences in preparation between repetition and alternation predictions. Results suggested that alternation predictions elicited stronger anticipatory activity, and that this difference was more pronounced the stronger participants were biased towards expecting repetitions. Taken together, these findings suggest an intricate interplay between proactive and reactive control influences.

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[1] This chapter is based on: Duthoo, W., Abrahamse, E.L.., Deschuymer, M., & Notebaert, W. (*Manuscript in preparation*). ERP correlates of proactive and reactive control in the Stroop task.

INTRODUCTION

Cognitive control entails selecting the appropriate action while at the same time shielding the cognitive system from various distracters that concurrently compete for attention in a stimulus-rich environment. Such acts of control typically benefit from prior knowledge about which events are likely to come across. Indeed, as highlighted in Kunde et al. (2007), anticipating the appropriate environmental conditions in order to efficiently prepare goal-directed actions is one of the prime abilities of the human neurocognitive system. Research on cognitive control has long been dominated by exploring how it is optimized in reaction to past events, thereby overlooking anticipatory control. The latter, however, has recently attracted renewed interest: Various experiments have shown that predictions about *what* future event is likely to happen (Duthoo, Wühr, & Notebaert, 2013; Duthoo, De Baene, Wühr, & Notebaert, 2012; Kemper et al., 2012; Umbach, Schwager, Frensch, & Gaschler, 2012) as well as expectancies about *when* these stimulus events will likely happen (Thomaschke, Wagener, Kiesel, & Hoffmann, 2011; Wendt & Kiesel, 2011) have a significant impact on stimulus encoding, response preparation and interference control. Building on our previous work (Duthoo et al., 2013), the current study recorded the EEG in order to investigate the neural correlates of prediction-driven adjustments in attentional control and elucidate how these interact with reactive, conflict-induced signals.

In the study of Duthoo et al. (2013), participants performed a Stroop conflict task in which they were asked on each trial to predict the congruency level of the upcoming stimulus. This revealed that participants display a bias towards expecting repeating congruency levels. Furthermore, much like in the studies of Umbach et al. (2012) and Kemper et al. (2013), participants seemed to have used these expectancies in preparing their response or attentional settings, even though they were not valid in predicting the stimulus. Interestingly, it was found that only when participants anticipated a repetition of the congruency level (after recoding participants' absolute predictions into predictions relative to the previous trial), strong behavioural adjustments were found. More specifically, a congruency sequence or *Gratton* effect (Gratton, Coles, & Donchin, 1992) – the finding of a reduced congruency effect following incongruent (I) as compared to congruent (C) trials – only emerged following repetition predictions. This sequential modulation has been typically interpreted as a reactive upregulation of control following conflict (Egner, 2007). The question that follows is precisely how these prediction-driven attentional adjustments interacted with reactive, conflict-induced control signals.

In line with the conflict monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen , 2001), reactive conflict regulation here refers to increasing controlled colour processing following incongruent trials, and decreasing this controlled colour processing after congruent trials. This model was further extended by Verguts & Notebaert (2008; 2009), who specified that conflict will strengthen the currently active task representations. In reaction to conflict, attention to the relevant dimension will thus be enhanced, and the influence of the irrelevant dimension reduced. This model similarly predicts a reduced congruency effect following incongruent trials. Taking reactive control one step further, Scherbaum, Fischer, Dshemuchadse, & Goschke (2011) proposed that participants can reactively detect and resolve conflict *within* the current trial (see also Ridderinkhof, 2002). These within-trial adaptations are then carried over to the next trial, leading to sequential adjustments in the size of the congruency effect (i.e., a CSE). In contrast to reactive control, proactive control is triggered by expectancy, rather than conflict on the previous trial. Proactive control here refers to preparatory attentional orienting, through which expectancies trigger top-down biases of relevant stimulus-response associations (see Kastner & Ungerleider, 2000). Such proactive adjustments can be systematically induced by, for example, providing informative or probabilistic cues (Aarts & Roelofs, 2011; Wühr & Kunde, 2008). Alternatively, proactive control can follow from more subjective biases. In the present study, such subjective biases were directly assessed, by measuring participants' predictions explicitly.

In our prediction Stroop task (Duthoo et al., 2013), these proactive and reactive control adjustments can be traced by verifying how known Stroop EEG markers are selectively affected by conflict on the previous trial and/or prediction type. Based on previous EEG investigations of Stroop conflict control (Larson, Kaufman, & Perlstein, 2009; Liotti, Woldorff, Perez III & Mayberg, 2000; Tang et al., 2013), we looked for interactions between predictions and previous conflict in an early, frontocentral component (the N450) suggested to reflect conflict detection, as well in a late, more sustained slow wave (the conflict slow potential; conflict SP), hypothesized to reflect Stroop conflict resolution on incongruent trials. The present investigation of these EEG markers has the further advantage of controlling for potentially confounding influences of feature integration (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003), since no relevant or irrelevant feature repeated over three consecutive trials (Duthoo & Notebaert, 2012). Importantly, this allowed a first ‘pure’ test of sequential modulation in the Stroop task, as previous EEG investigations included both colour/word repetition and negative priming transitions in their design (Larson et al., 2009; Tang, Hu, Zhang, & Chen, 2013). These previous studies reported that the conflict slow potential was modulated by the previous trial, thought to reflect reactive adaptation to conflict. The N450, on the other hand, appeared only sensitive to conflict on the current trial.

We further explored the anticipatory effects of predictions prior to stimulus onset by looking at the contingent negative variation (CNV) for repetition and alternation predictions. Previous studies have already suggested that the CNV not only reflects motivation or motor preparation (Leuthold & Jentschz, 2001; Lorist et al., 2000), but also anticipatory attention and preparatory control (Fan et al, 2007; Strack, Kaufmann, Kehrer, Brandt, & Stürmer, 2013). More specifically, we investigated potential differences in preparation following alternation and repetition predictions. This allowed differentiating between two alternative interpretations for the absence of a CSE following alternation predictions (Duthoo et al., 2013). First, this could reflect the net effect of simultaneously active reactive, conflict-induced adjustments and proactive, expectancy-based adjustments cancelling each other out following an alternation prediction. Alternatively, this could be explained by assuming that participants refrain from preparing when predicting an alternation, and adopt a ‘neutral’ control mode – thereby blocking the control processes that were reactively elicited on the previous trial (Scherbaum et al., 2011). In case participants equally prepare proactively for congruency level alternations and repetitions, we predict to find no early, preparatory differences between alternation and repetition predictions. If, however, participants refrain from preparing following an alternation, we expect stronger preparation (i.e., a stronger CNV) for repetition compared to alternation predictions. As we can consider the measured predictions as an extra index of cognitive control, we also looked how preparation for repetition and alternation trials is influenced by the strength of the repetition bias. Therefore, individual differences in participants’ bias to expect repeating congruency level are also taken into account.

METHOD

PARTICIPANTS

A group of 17 Ghent University students (12 females; 5 males; ages 18-23) provided written informed consent to participate in the experiment, approximately lasting one hour and a half. They received 25 euro as compensation. All participants reported to have normal of corrected-to-normal vision. None of the patients had a history of neurological or psychiatric disease. One participant, whose mean error rate exceeded more than 2 SD of the grand mean, was rejected from further analysis.

STIMULI AND APPARATUS

A program written with T-Scope software controlled the experiment (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 2006). Stimuli were displayed on a 17-inch monitor, with a viewing distance of approximately 60 cm. All text was presented in Courier, size 20. Stimuli consisted of eight (Dutch) colour words presented in one of the eight possible colours (red, green, blue, yellow, pink, brown, purple or gray). Participants had to react by saying out loud the font colour, and responses were detected by means of a Sennheiser MD 421-U-4 microphone optimized for reaction time experiments (e.g., Duyck et al., 2008).

DESIGN AND PROCEDURE

Equal numbers of congruent and incongruent stimuli were presented. In order to rule out an explanation of sequential modulations in terms of episodic memory bindings (see, e.g., Hommel et al., 2004), we constrained random selection of colour and colour word by precluding complete stimulus repetitions or relevant or irrelevant feature repetitions, relative to both trial *n*-1 and *n*-2. In other words, all stimulus and response features changed across three consecutive trials (see Duthoo & Notebaert, 2012).

Participants were presented with two practice blocks of 90 regular Stroop trials. They then completed a second practice block containing 15 Stroop trials, during which they not only had to predict the congruency level of the upcoming trial (congruent or incongruent), by clicking the left or right button of a response box (counterbalanced) that was placed on the table in front of the participants, but also to report afterwards whether or not their prediction was confirmed, again by clicking the appropriate response box button. The data revealed that all participants understood the basic idea of the experiment, since all participants judged their predictions accurately above chance level. Finally, six experimental blocks of 90 trials were presented, during which participants had to make predictions about the difficulty (congruent was termed ‘easy’, incongruent ‘difficult’) of the upcoming stimulus and subsequently respond accurately to it. They were supposed to predict the next trial correctly and instructed to respond as fast as possible while at the same time minimizing their number of errors. A store coupon was rewarded to the participants who performed best, taking into account both the number of correct predictions, mean reaction times and error percentages.

Each trial started with the presentation of a fixation dot for 700 ms. For the two practice blocks of regular Stroop trials, the stimulus word then appeared on screen until a response was registered by the microphone, with the maximal reaction time restricted to 2000 ms. During the six experimental blocks, participants’ predictions were probed before the actual Stroop stimulus appeared on screen, by presenting the instruction ‘Next trial?’ on screen until participants clicked one of the two response box buttons, followed by a fixation dot for 1000 ms. The moment the voice key was triggered in response to the Stroop stimuli, the stimulus word shortly tilted 20° to the right for 300 ms before the fixation dot reappeared on the screen and the experimenter coded the actual response given by the subject (thereby jittering the RSI). When the voice key was triggered too early (caused by a noise other than the participant’s voice) or too late (because of the participant hesitating, hissing or raising the voice during the response), the experimenter coded the trial as a false alarm. A scheme of the experimental procedure described above is visualized in Figure 1.

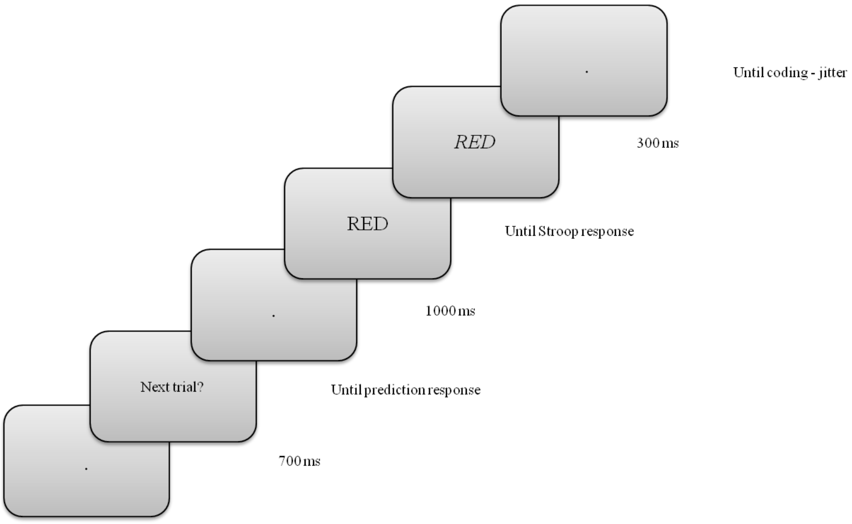

Figure 1: Timing values and sequence of events for one trial of the experimental procedure. The prediction prompt 'Next Trial' remained on the screen until a prediction response was detected. Similarly, the Stroop trial remained on screen until a vocal response was detected by the voice key. Following response registration, the Stroop stimulus shortly tilted to the right for 300 ms, after which the experimenter coded the response, thereby jittering the response-to-stimulus interval.

EEG DATA PROCESSING

All EEG processing was performed using the MATLAB extension EEGLAB (Delorme & Makeig, 2004) and the EEGLAB plug-in ERPLAB (Lopez-Calderon & Luck, 2010). The continuous EEG signal was filtered off-line with a high-pass filter of 0.16 Hz and down-sampled to 256 Hz. Independent component analysis (ICA) was conducted to identify and remove stereotypical eye blink and horizontal eye movement components. Next, a blind source separation algorithm on the basis of canonical correlation analysis (BSS-CCA; De Clercq, Vergult, Vanrumste, Van Paesschen, & Van Huffel, 2006) was applied in order to reduce the EMG artefacts in the EEG at the moment of the response, induced by articulation during our vocal Stroop task procedure (see also De Vos et al., 2010; Riès, Janssen, Dufau, Alario, & Burle, 2010). Remaining artefacts were rejected by visual inspection of all traces, guided by automatic artefact detection algorithms that marked segments with amplitudes exceeding ±200 μV or transitional sample-to-sample thresholds of 150 μV, as well as segments for which the difference between the most positive and most negative peak in a moving window of 200 ms exceeded 150 μV.

ERP DATA ANALYSIS

We first recoded participants' absolute predictions about the upcoming congruency level relative to the congruency level of the previous trial, thereby creating congruency level *repetition* and *alternation* predictions. For the pre-stimulus EEG data, we focused on predictions that followed on correct Stroop trials, excluding segments following on an incorrect response or voice key error. Predictions faster than 200 ms or slower than 1000 ms were not analyzed. As a consequence, the data of one participant did not enter the prediction analysis, because of a data rejection rate that was more than 2 SD higher than the grand mean. For the other 15 participants, this data trimming procedure excluded on average 16.7% (SD = 6.7) of segments. In a next step, artefact detection routines described above led to the removal of another 3.3% (SD = 2.7) of the remaining data.

Next, cue-locked segments starting 200 ms before until 2200 ms after the onset of the prediction prompt (i.e., 'Next trial?') were created. The 200 ms prior to cue onset served as a baseline. Effects of predictions were analyzed at electrode Cz and the two adjacent electrode sites C1 and C2 (similar to Fan et al., 2007), in the time-window between 400 and 1200 ms. The latter time-point (1200 ms) refers to the earliest moment in time (given the fastest prediction reaction time of 200 ms and a 1000 ms preparatory interval) where sensory processing of the Stroop stimulus influenced the ERP[2]. Measured voltages were averaged across sites prior to analyses.

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[2] We opted for a cue-locked analysis of the data rather than prediction-locked analysis for two reasons. First, we assumed that preparatory activity started before

For the post-stimulus EEG analysis of Stroop performance, incorrect trials, trials following on an error or voice key failure, as well as reaction times not fitting the outlier criterion (<300 ms or >1500 ms) were excluded from the individual-subjects ERP averages (M = 14. 3%, SD = 5.4). In a next step, the artefact detection routines described above led to the exclusion of one participant, since more than half of the available trials were contaminated by artefacts. For the remaining 15 participants, artefact detection led to the exclusion of 4.7% (SD = 6.7) of the remaining data.

The EEG was segmented into condition-related epochs time-locked to stimulus presentation, starting from 200 ms before until 1500 ms after stimulus offset. Then, averages for each congruency sequence (CC, CI, IC, II) were derived separately for repetition and alternation predictions. The resulting ERPs were baseline-corrected using the 200 ms pre-stimulus window. Selection of the electrode sites for the electrophysiological analysis was based on previous findings reporting early fronto-medial and late posterior-parietal Stroop conflict ERP modulations (Larson et al., 2009; Liotti et al., 2000), confirmed by inspection of the scalp distribution maps of the current data (see Figure 4). The phasic fronto-central N450 was quantified as the mean voltage between 350 and 500 ms at FCz and adjacent FC1 and FC2 electrode sites. Following visual inspection of the incongruent minus congruent difference wave, the more tonic conflict SP was quantified as the mean voltage from 600 to 850 ms at Pz and adjacent P1 and P2 electrode sites. Measured voltages for both components were averaged across sites prior to analyses.

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participants made the prediction. Second, cue-locked analysis allowed a ‘neutral’ baseline period before cue-onset, whereas prediction-locked segments did not allow an easy choice of baseline. Still, an identical analysis on the prediction-locked data (corrected with respect to a longer baseline period between 1000 and 200 ms prior to predictions) yielded similar results.

RESULTS

BEHAVIOURAL

Predictions. On average, participants' predictions matched the congruency level of the previous trial on 62% (SD = 9.7) of their choices, replicating the congruency level repetition bias reported in Duthoo et al. (2013). A one-sample *t*-test revealed that this percentage exceeded chance level significantly, *t*(15) = 5.1, *p* < .001. Moreover, there was no significant difference between participants' repetition bias following congruent (61%, SD = 12) or incongruent trials (64%, SD = 11), *t*(15) < 1, *ns*.

Stroop Performance. For the RT analysis, we first excluded voice key failures (M = 5.4%, SD = 2.4), errors (M = 2.1%, SD = 1.4), reaction times not fitting the outlier criterion (<300 ms or >1500; M = .09%, SD = 1.1) as well as trials following on an error or voice key failure (M = 6%, SD = 2.5), amounting to a total of 14.3% (SD = 5.4). Then, we ran a repeated-measures ANOVA with the within-subjects factors Prediction Type (two levels: repetition and alternation), Previous Congruency (two levels: congruent and incongruent) and Current Congruency (two levels: congruent and incongruent). After standardization, the actual amount of expected congruency level repetitions entered the ANOVA as a covariate Results revealed a significant three-way interaction, *F*(1, 14) = 16.82, *p* < .01. When participants expected a repetition of congruency level, a significant interaction between previous and current congruency (i.e., a CSE) was found, *F*(1,14) = 88.79, *p* < .001, that was absent when an alternation of congruency level was expected, *F*(1,14) = .27, *p* = .6. This difference in the CSE between alternation and repetition predictions is depicted in Figure 2. The repetition bias did not interact with any of the interactions above (all *p* > .58).

Mean accuracy was near ceiling (97.9%, SD = 1.4). Running the same repeated-measures ANOVA on the mean error rates, revealed only a significant effect of Current Congruency, *F*(1, 14) = 12.38, *p* < .01. The interaction between Previous and Current Congruency, indicating a CSE, revealed only a trend, *F*(1, 14) = 2.79, *p* = .12. No significant three-way interaction was found, *F*(1, 14) = .46, *p* = .51. However, as the distinction between technical errors and performance errors is blurry (e.g., when participants correct their responses), these results have to be interpreted with caution (but see Duthoo et al., 2013, for evidence that error percentages follow a similar pattern as reaction times in a manual version of the prediction Stroop task that allowed proper error analysis).

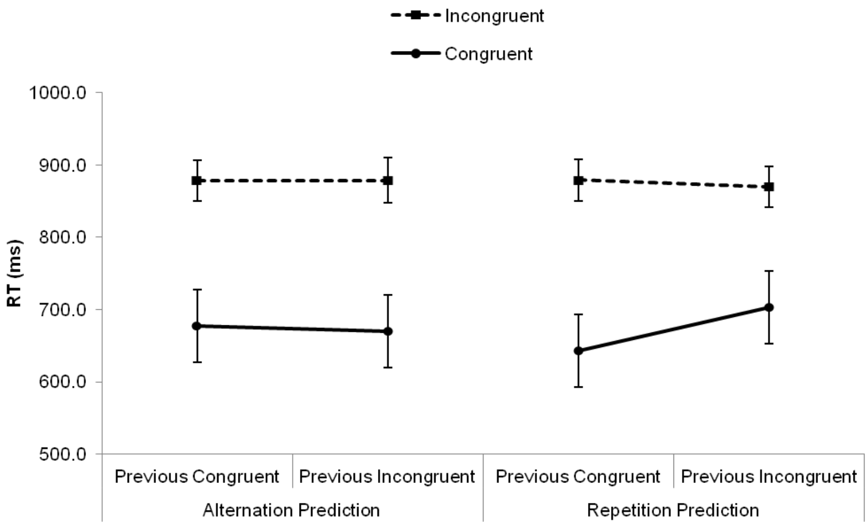

Figure 2: Mean reaction times (RTs, in milliseconds) incongruent (dashed line) and congruent (solid line) trials as a function of the congruency level of the previous trial, separately for alternation and repetition predictions. Error bars represent 95% confidence intervals around the mean.

ERPS

Predictions. A repeated-measures ANOVA with the within-subjects factor Prediction Type (two levels: repetition and alternation) and Congruency (two levels: congruent and incongruent) on the averaged mean voltages over the selected central electrodes during the pre-stimulus interval tested whether the CNV differed between experimental conditions. After standardization, the amount of actually predicted congruency level repetitions entered the ANOVA as a covariate[3]. For plotting purposes (but not for statistical analyses), the ERP data was filtered with a 5 Hz low-pass filter.

The repeated-measures ANOVA revealed a significant main effect of Prediction Type, $F(1, 13) = 5.79$, $p < .05$. This indicated that the mean voltage was significantly more negative for alternation than repetition predictions, as visualized Figure 3A. This main effect of Prediction Type further interacted significantly with the participants' actual amount of repetition predictions, $F(1, 13) = 6.24$, $p < .05$. This interaction pointed to the fact that this difference in the CNV between predictions was more pronounced the stronger participants displayed a repetition bias. When subtracting the mean amplitude voltage for repetition predictions from that of alternation predictions, the obtained difference score significantly correlated with participants' repetition bias, $r = -.52$, $p < .05$, as visualized in Figure 4B. Both the main effect of Congruency and the interaction between Congruency and Prediction Type did not reach significance (*p*s > .30).

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[3] We used these standardized values for the ANOVA. For plotting purposes, however, we used the actual (not standardized) values.

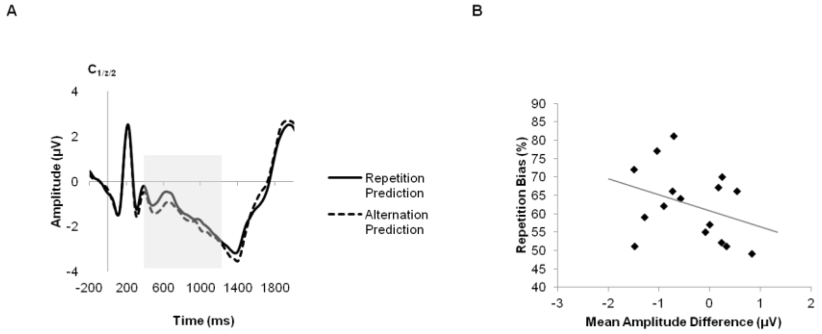

Figure 3: Cue-locked grand-average ERPs for repetition and alternation predictions averaged over selected central electrodes (A). The CNV was calculated as the mean amplitude between 400 and 1200 ms, visualized by the grey box. The scatter plot (B) depict the correlation between participants' congruency level repetition bias and the mean amplitude difference of the CNV (alternation minus repetition predictions). Negative values denote a larger CNV for alternation compared to repetition predictions.

Stroop Performance. The grand average waveforms for congruent and incongruent trials and scalp distribution maps of the incongruent minus congruent (i.e., Stroop conflict) difference wave in the time window of interest are depicted in Figure 4, revealing the classic N450 in the 350-500 ms time-window as well as a conflict slow potential in the 600-850 ms time-window.

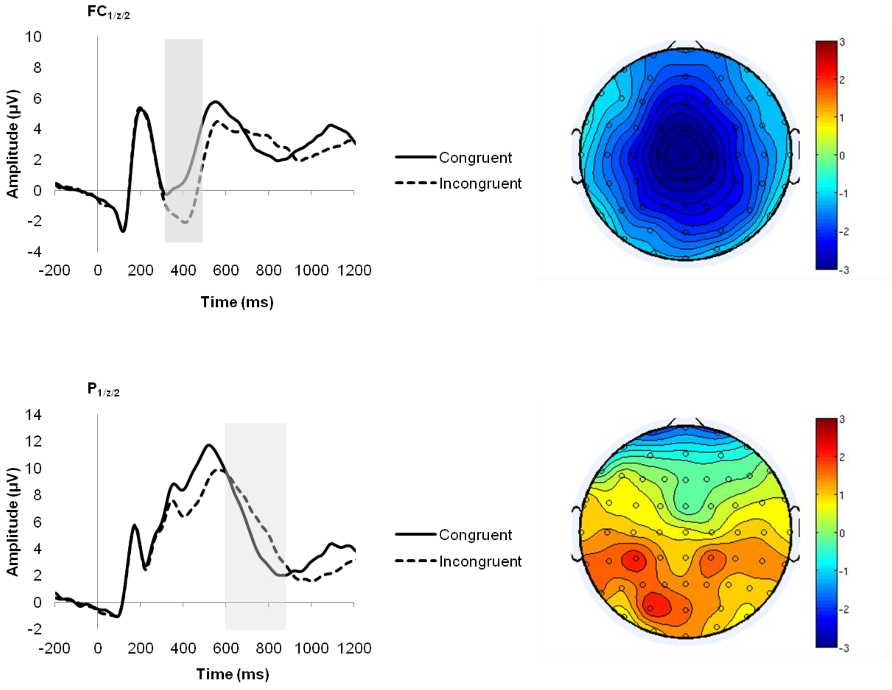

Figure 4: Stimulus-locked grand-average ERPs averaged over selected fronto-central and parietal electrodes for incongruent (dashed line) and congruent (solid line) trials. On the right, the scalp distribution maps for the incongruent minus congruent difference wave between 350 and 500 ms and between 600 and 850 ms are depicted.

We ran a repeated-measures ANOVA with the within-subjects factor Prediction Type (two levels: repetition and alternation), Previous Congruency (two levels: congruent and incongruent) and Current Congruency (two levels: congruent and incongruent) on the N450 and conflict SP mean voltages. Again, the amount of actually predicted congruency level repetitions entered the ANOVA as a covariate. For plotting purposes (but not for statistical analyses), the ERP data was filtered with a 15 Hz low-pass filter.

Analysis of the N450 revealed a significant main effect of Current Congruency, $F(1,13) = 20.30$, $p < .01$, indicating a more negative mean amplitude for incongruent compared to congruent trials. The main effect of

Previous Congruency also was significant, *F*(1,13) = 9.05, *p* < .05, indicating a stronger N450 for trials having incongruent compared to congruent predecessors. The interaction between Current and Previous Congruency did not reach significance, *F*(1,13) = .60, *p* = .45. However, mirroring the RT results, a significant three-way interaction between Prediction Type, Previous Congruency and Current Congruency, *F*(1,13) = 5.11, *p* < .05, was found. Following repetition predictions, the main effect of Current and Previous Congruency were both significant [*F*(1,13) = 14.67, *p* < .05 and *F*(1,13) = 10.64, *p* < .05, respectively]. The interaction between Previous and Current Congruency was marginally significant, *F*(1,13) = 3.74, *p* = .075. Following alternation predictions, only a significant main effect of Current Congruency was found, *F*(1,13) = 19.09, *p* < .01. All other effects were nonsignificant (all *F*s < 1.56, *p*s > .23). Follow-up paired-samples *t*-tests revealed that this difference in the sequential modulation of the N450 between repetition and alternation predictions, depicted in Figure 5, was mainly due to a more negative N450 amplitude for IC compared to CC transitions following repetition predictions, *t*(14) = 3.32, *p* < .01, that was absent following alternation predictions, *t*(14) = .61, *p* = .55. Comparisons between CI and II trial transitions were not significant for both prediction types (all *t*s < .16, *p*s > .12).

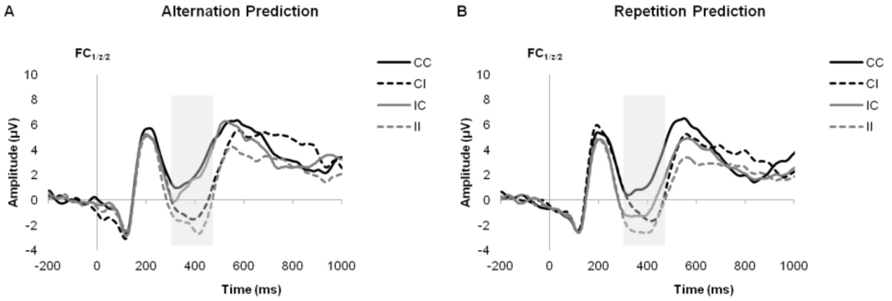

Figure 5: Stimulus-locked grand-average ERPs averaged over selected fronto-central electrodes for incongruent (dashed line) and congruent (solid line) as a function of whether the previous trial was congruent (black line) or incongruent (grey line), separately for alternation (A) and repetition (B) predictions.

Next, the conflict SP mean amplitude data entered the repeated-measures ANOVA. In contrast to the RT and N450 data, the three-way interaction between Prediction Type, Previous Congruency and Current Congruency was not significant, *F*(1,13) = .78, *p* = .39. Yet, the interaction between Previous Congruency and Current Congruency, *F*(1,13) = 6.259, *p* < .05, was significant, indicating the presence of a congruency sequence effect in the conflict slow potential, irrespective of predictions. Follow-up paired-samples *t*-tests revealed that the sequential modulation of the CSP is mainly driven by a reduction in mean amplitude for II compared to CI trial transitions, *t*(14) = 2.51, *p* < .01. The reduction in mean amplitude for CC compared to IC trial transitions was not significant, *t*(14) = 1.69, *p* = .11.

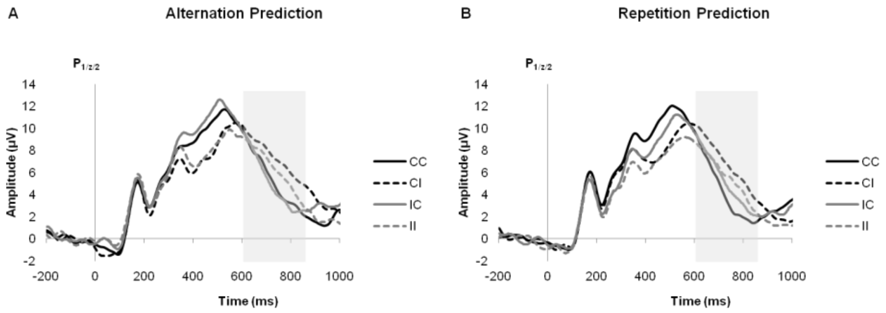

Figure 6: Stimulus-locked grand-average ERPs averaged over selected parietal electrodes for incongruent (dashed line) and congruent (solid line) as a function of whether the previous trial was congruent (black line) or incongruent (grey line), separately for alternation (A) and repetition (B) predictions.

GENERAL DISCUSSION

The current study investigated how predictions about the upcoming congruency level influenced subsequent Stroop processing and interacted with reactive control adjustments (i.e., conflict adaptation or congruency sequence effects (CSEs); Botvinick et al., 2001; Egner, 2007; 2008). To this end, we verified the impact of predictions in reference to the congruency level of the previous trial and contrasted the congruency sequence effect for repetition and alternation predictions. Replicating our previous results (Duthoo et al., 2013), we showed that participants were biased to predict congruency level repetitions. Only following these repetition predictions, a reliable CSE was found. Following alternation predictions, this CSE was, on average, absent. To better understand this pattern, we investigated whether repetition and alternation predictions differed in the relative amount of preparatory control, as reflected in the CNV, and traced the influence of conflict on the previous trial and prediction type on known EEG markers of Stroop performance.

PREPARING FOR SELF-PROPHESISED CHANGE

When looking at the interval during which predictions were assumed to evoke preparatory activity in anticipation of the upcoming trial (see Umbach et al., 2012, for further evidence), results revealed a modulation of the contingent negative variation (CNV; Walter, Cooper, Aldridge, McCallum, & Winter, 1964) for repetition and alternation predictions. Previous studies have already suggested that not only motivation or motor preparation (Leuthold & Jentschz, 2001; Lorist et al., 2000), but also anticipatory attention (Fan et al, 2007; Strack et al., 2013) are indexed by the CNV (see Brunia, van Boxtel, & Böcker, 2011, for a review). The CNV data indicated that alternation predictions, on average, elicited stronger preparatory activity. Moreover, the difference in the CNV between repetition and alternation predictions crucially depended on participants' bias to expect congruency level repetitions.

These findings are reminiscent of study by Vandamme, Szmalec, Liefooghe, & Vandierendonck (2010), who looked at EEG correlates of the task repetition bias in voluntary task switching (Arrington & Logan, 2004). These authors found that when participants voluntarily decided to switch tasks, a stronger CNV was observed. However, they did not correlate this difference in CNV to participants' task repetition bias. As Stroop task performance also involves task conflict (Aarts, Roelofs, van Turennout, 2009; Steinhauser & Hübner, 2009), our findings may similarly suggest that predicting (and preparing) a task switch (changing from word reading to colour naming or vice versa) elicited stronger CNV activity, or, more generally, that context alternations increase demands on cognitive control.

A recent study on anticipatory control in the Simon task by Strack et al. (2013) reported that rule (i.e., congruency) cues elicited a larger CNV compared to non-informative cues as well as cues signalling the position of the upcoming Simon conflict trial. As subsequent Simon conflict was effectively abolished following these rule cues, it was also assumed that stronger CNV activity reflected active preparation for the upcoming trial. However, much like in our study and in their previous research (Alpay, Goerke, & Stürmer, 2009), they failed to find differences in preparatory CNV activity between cues signalling congruent and incongruent trials.

The current data do not suggest that participants refrained from preparing in anticipation of a congruency level alternation, but rather point to the contrary, especially when a strong repetition bias had to be overcome. This suggests that the lack of CSE for alternation predictions more likely reflects interactive effects between proactive, prediction driven adjustments, and reactive signals triggered by processing conflict on the previous trial. These interactions were further explored in known markers of Stroop conflict processing and resolution, reported below. Yet, one could also argue that the CNV does not reflect preparation but rather the prediction process itself. The correlation between the CNV effect (alternation minus repetition) and the choice bias speaks in favour of this hypothesis, as it is reasonable to assume that predicting an alternation requires more processing when one is biased more strongly to predict repetitions. In this view, the larger CNV for alternations might reflect the process of overcoming the repetition bias. However, the temporal pattern of the CNV suggests otherwise. The fact that the CNV effect lasts over the preparatory interval indicates that this process continues even after the prediction has been made, and therefore favours an interpretation in terms of preparatory processes. Initial attempts to correlate the CNV effect with neural or behavioural indices of Stroop performance, however, failed. The correlation between the choice bias and the CNV effect could be interpreted as reduced preparation for repetition predictions (compared to alternation predictions) for participants with a strong repetition bias. This would indicate that the stronger the repetition bias, the more participants are tuned towards congruency level repetitions, both in terms of predictions and in terms of preparation, hence requiring less additional preparatory processes. However, more research will be needed to fully understand the functional meaning of the CNV and its relation to behaviour.

SEQUENTIAL STROOP PERFORMANCE

The vocal 8-colour Stroop task that was applied in the present study effectively excluded all potentially confounding influences of feature integration (Duthoo & Notebaert, 2012), and therefore was ideally suited to investigate both reactive, conflict-induced sequential modulation, and the impact of predictions on these reactive adjustments. Analysis of the mean N450 amplitude showed a modulation of the influence of previous congruency that was dependent on the preceding prediction type, much like the reaction time analysis. Crucially, the analysis revealed that following repetition predictions, both current incongruent trials and trials following on an incongruent trial showed a strong N450 (compared to CC trial transitions). Following alternation predictions, the N450 was not modulated by the previous trial's congruency level, and no difference between IC and CC trials was found. Both aspects of these results – the difference in N450 between CC and IC trials following repetition predictions and its absence following alternation predictions – merit some further discussion.

Even though the overall interaction between previous and current congruency did not reach significance, replicating previous research in the Stroop task for both the visual (Larson et al., 2009) and auditory modality (Donohue, Liotti, Perez III, & Woldorff, 2012), the pattern of the N450 following repetition predictions clearly suggested an influence of the previous trial on the processing of the current trial. Whereas Donohue et al. (2012) did not provide figures or further statistics, the plot of the sequential

N450 effect in the study of Larson et al. (2009; p. 666) suggests a descriptively similar pattern (i.e., a more negative N450 peak for IC compared to CC trials). Consistent with our findings, previous studies that manipulated the proportion of incongruent trials (and, consequently, the proportion of IC versus CC trial transitions) have generally found that the difference in the N450 between congruent and incongruent trials disappeared in conditions with a high proportion of incongruent trials (Lansbergen, van Hell, & Kenemans, 2007; Tillman & Wiens, 2011). Indeed, under such conditions, congruent trials are more often preceded by an incongruent trial, as reflected in a negative deflection of comparable size as for incongruent trials. Tillman and Wiens (2011) found opposite effects for the N2 amplitude (e.g., a more pronounced difference in high conflict conditions) in a flanker task, and previous studies consistently revealed a sequential modulation (CI compared to II trials) of the N2 (Clayson & Larson, 2012; Larson, Clayson, & Baldwin, 2012). This suggests that the N450 and N2 do not reflect the same underlying mechanism.

Importantly, our findings question the notion that the N450 reflects the detection of conflict. Conflict detection is not assumed to play a role in the processing congruent trials, but still we observed a strong N450 for congruent trials following on an incongruent trial (after repetition predictions). Furthermore, an explanation of the difference between IC and CC transitions following repetition predictions in terms of expectancy violation (see Kemper et al., 2013) or inappropriate strategy implementation (Bartholow et al., 2005) would predict and equally strong effect for unexpected CC compared to IC trials following alternation predictions, and an even larger N450 for unexpected CI compared to II trials following repetition predictions. Instead, the N450 pattern is more consistent with a reactive control account, postulating increased control (e.g., suppression of the word reading process), that is activated in reaction to processing the current incongruent trial as well as triggered (or carried over) by the processing of incongruent Stroop words on the previous trial (Scherbaum et al., 2011; Verguts & Notebaert, 2008; 2009). In this light, proactive control processes in the current study then entailed selectively overriding this controlled suppression of word reading following alternation predictions, thereby reducing the N450 for IC trials. In the RT pattern, this was reflected in a speed-up of IC trials following alternation compared to following repetition predictions, $t(15) = 4.40$, $p < .01$.

In line with previous investigations (Donohue et al., 2012; Larson et al., 2009; Tang et al., 2012), analysis of the conflict SP revealed an interaction between previous and current congruency. This slow potential component, characterized by a parietal positivity and accompanying frontal negativity, has been consistently found in conditions where interference is increased (Liotti et al., 2000; West, 2003) and has also been suggested to reflect control processes implemented to resolve interference in conflicting (Larson et al., 2009) or bivalent (Rey-Mermet, Koenig, & Meier, 2013) stimuli. The observation that it was modulated by the congruency level of the previous trial, irrespective of participants’ expectancies, corroborates the suggestion that this component crucially reflects reactive adaptation to conflict. This was reflected in a less pronounced conflict SP for II compared to CI trials. Therefore, we interpret this finding to reflect activity of an attentional control system that biases attention to relevant stimulus information (Egner & Hirsch, 2005), in line with the notion that the parietal cortex is crucially involved in the resolution of stimulus-based conflict (Egner, Delano, & Hirsch, 2007; Tang et al., 2013).

In conclusion, our results suggest that alternation predictions do evoke preparatory activity, as reflected in a stronger CNV for predicted incongruent alternations. Yet, the EEG analysis revealed that performance in our prediction Stroop task seems to reflect an intricate interplay between proactive and reactive control processes. Firstly, the N450 appeared both sensitive to prediction type and the congruency level of the previous trial. More specifically, next to being more pronounced for incongruent than congruent trials, the N450 was enhanced for IC compared to CC trials. This finding questions the notion that this component reflects conflict detection (Larson et al, 2009; West, 2003), but rather suggests it to reflect a form of control implemented to avoid early response capture by the word's meaning. The N450 also seemed sensitive to expectancy-based adjustments, as it was greatly reduced for IC trials following alternation predictions. This was interpreted as a proactive, strategic tuning down of reactive control, speeding up performance on these IC trial transitions. Contrary to the N450, the conflict SP was only modulated by the congruency level of the previous trial, irrespective of participants' expectancies. This is best captured in terms of reactive control models (Botvinick et al., 2001; Verguts & Notebaert, 2008; 2009), according to which attention to the task-relevant stimulus dimension is strengthened following conflict on the previous trial. Taken together, the present study showed that proactive and reactive control processes can tightly work together in order to engage in an optimal processing strategy to better adapt to the task at hand.

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CHAPTER 6

GOING, GOING, GONE? PROACTIVE CONTROL PREVENTS THE CONGRUENCY SEQUENCE EFFECT FROM RAPID DECAY[1]

The congruency sequence effect, the finding of a reduced congruency effect following incongruent trials in conflict tasks, has dominated the research on cognitive control over the last two decades. This effect can reflect either expectancy-guided preparatory biasing in anticipation of the upcoming stimulus (i.e., proactive control), or phasic enhancement of the attentional set in response to conflict on the previous trial (i.e., reactive control). A recent study by Egner, Ely, & Grinband (2010) set out to contrast these two alternatives, by exploring the congruency sequence effect across a wide range of inter-trial intervals. It was found that congruency sequence effects were subject to rapid decay over time. This decay fits well with the notion of reactive control, while at the same time speaking strongly against the involvement of proactive regulation – which should also (and even mainly) be evident at longer intervals. In the present study, we first replicate a reduction of the congruency sequence effect over successive response-to-stimulus intervals (RSI) in a face-word Stroop task. In a second experiment, we then show that congruency sequence effects are observed at longer intervals, too, when the proportion of trials involving longer intervals is increased. These findings suggest a contribution of proactive regulation to congruency sequence effects, once conditions are rendered more favourable to commit to such.

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[1] This chapter is based on: Duthoo, W., Abrahamse, E.L., Braem, S., & Notebaert, W. (*Manuscript submitted for publication*). Going, going, gone? Proactive control prevents the congruency sequence effect from rapid decay.

INTRODUCTION

Attention regulation and action planning is determined by situational factors in our everyday environment. Past studies have mainly focused on describing these phenomena as simple action-reaction mechanisms, while the role of proactive, anticipatory action and attention regulation remain insufficiently explored (but see Braver, 2012; Braver, Gray, & Burgess, 2007). In the present study, we set out to contribute to this issue by investigating the role of expectancies in trial-to-trial adaptations of cognitive control. More specifically, we explored the influence of a response-to-stimulus interval (RSI) proportion manipulation on the congruency sequence effect (CSE), an influential marker of cognitive control that inspired a wealth of behavioural and theoretical studies over the last two decades (see Egner, 2007; 2008, for a review).

Congruency sequence effects (CSEs; also known as sequential or *Gratton* effects; Gratton, Coles, & Donchin, 1992) refer to the observation that congruency effects are typically smaller after an incongruent than after a congruent trial. The mechanisms driving these sequential effects are subject to some major debates. Most prominently, the theoretical discussion centred on the question whether top-down, attentional control modulation (Botvinick, Braver, Barch, Carter, & Cohen, 2001) or bottom-up, associative learning (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003; Schmidt & Besner, 2008) is the driving force behind these adjustments. Empirical studies aimed at disentangling these influences rendered it unlikely that the CSE can solely be explained by bottom-up effects of feature binding (Akçay & Hazeltine, 2011; Duthoo & Notebaert, 2012; Kerns et al., 2004; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Notebaert & Verguts, 2007; Ullsperger, Bylsma, & Botvinick, 2005). The experiments reported in the current study, following Egner, Ely, & Grinband (2010), were designed to keep associative effects constant across trial transitions.

Therefore, we do not provide an in-depth discussion of possible feature integration effects (see Duthoo & Notebaert, 2012; Schmidt, 2013).

Instead, we focused on a second major debate, situated *within* the perspective that CSEs reflect top-down attentional modulation rather than bottom-up associative learning. Specifically, it has been extensively discussed whether this attentional modulation is applied proactively or reactively. When the CSEs were first reported by Gratton et al. (1992), these authors interpreted them from a *proactive*, expectancy-based account, in which attention modulation is driven by active preparation for the upcoming stimulus, under the assumption that participants expect the congruency to repeat (as recently evidenced by a general congruency level repetition bias; see Duthoo, Wühr, & Notebaert, 2013, for support). However, others soon proposed a more *reactive* account, according to which the CSE is thought to reflect conflict-triggered enhanced attention to task-relevant information in order to maintain goal-directed behaviour – so-called *conflict adaptation* (Botvinick et al., 2001; Verguts & Notebaert, 2008; 2009). More specifically, these theories postulate that the detection of concurrently activated and incompatible stimulus or response representations (i.e., conflict) results in a transient strengthening of the current task set.

In a recent study, Egner et al. (2010) aimed to contrast proactive and reactive attention modulation accounts by exploring the time-course of CSEs. Specifically, they reasoned that whereas reactive effects can be assumed to be phasic, short-lived and thus subject to decay over time, proactive effects would take time to develop and remain more stable over time. By manipulating the inter-stimulus-interval (ISI) or response-stimulus-interval (RSI) they showed that – in line with reactive accounts – CSEs are observed with short intervals (from 500 ms up to 3000 ms for ISI and up to 2000 ms for RSI), yet disappear with longer ISIs and RSIs. Hence, as was later also emphasized by Van den Wildenberg, Ridderinkhof and Wylie (2012), this strongly suggests that adaptive attentional control is transient in nature.

However, this conclusion from Egner at al. (2010) and Van den Wildenberg et al. (2012) does not fit well with a small set of studies that provided support for proactive control in CSEs. Aarts and Roelofs (2011), for example, demonstrated that explicit cues predicting the upcoming congruency level with a certain probability also give rise to CSEs (see also Gratton et al., 1992), suggesting that not only experienced but also expected conflict (or absence thereof) can drive these sequential adjustments. Next, Duthoo et al. (2013) showed that self-generated congruency level repetition predictions also produced CSEs. Finally, Wendt and Kiesel (2011) reported support for the idea that proactive, temporal expectations can also strategically optimize attention allocation in anticipation of the specific to-be-expected congruency level of the stimulus. To this end, they manipulated associations between stimulus foreperiods of different length and the proportion of conflict trials. When the long foreperiod was associated with an 80% chance of an incongruent trial, the authors found a reduced interference effect compared to the short foreperiod associated with 20% conflict trials. Importantly, no conflict modulation was found when the short foreperiod was associated with a high conflict probability, implying that expectancy-based interference control benefitted from longer preparation time.

Moreover, the conclusion of Egner et al. (2010) and Van den Wildenberg et al. (2012) that adaptive attentional control is transient in nature may be premature when one considers the experimental design of the former study. Egner et al. (2010) themselves actually claimed that it was “quite favourable to the possibility of expectation-mediated improvements in performance at longer intervals, because the uniform distribution of ISI/RSI intervals produced an exponentially growing hazard function across the post-stimulus/response intervals”. Indeed, as also suggested by the study of Wendt and Kiesel (2011), proactive, expectancy-based attention modulation may be optimally exploited when one not only knows *what* to expect (i.e., the congruency level), but also *when* to expect this. Yet, proactive control should also be considered more effortful than reactive control (Braver, 2012;

Braver, Gray, & Burgess, 2007; Locke & Braver, 2008). This suggests that it is most efficiently applied when preparation can be timed as well: knowing when it is most needed, avoids the high effort of needing to be prepared all the time. Apart from the fact that the probability of stimulus presentation in the study by Egner et al. (2010) increased with each passing interval, the random distribution of 10 different RSI or ISI levels may have hindered the formation of accurate temporal predictions, as the stimulus may occur at any moment in time. Under these circumstances, active and constant preparation becomes a requirement for effective proactive control, and this would – possibly – render it too effortful for people to commit to it. We here hypothesized that participants do not always take this effort – especially not in a demotivating laboratory task – and thus rely more heavily on reactive control. Indeed, as also indicated by Egner et al., Wühr and Ansorge (2005) employed ISIs of 1500 and 6000 ms and still witnessed a CSE at the longer interval – possibly because proactive control could be prepared for and implemented at a very specific point in time, thereby decreasing the overall effort as compared to more gradual interval transitions.

To firmly enable the conclusion that CSEs are reactive rather than strategic in nature, one should also explore a design that is customized to optimally induce and/or steer proactive regulation. In the literature, proportion manipulations are typically employed to this purpose. For example, increasing the proportion of incongruent trials in the context of a conflict task reduces the congruency effect, and this is typically attributed to proactive, sustained cognitive control (Logan & Zbrodoff, 1979; Bugg & Chanani, 2011; see Bugg & Crump, 2012, for a review). Moreover, within the domain of cognitive control, the proportion manipulation has also been applied to fore-periods (Wendt & Kiesel, 2011), or the proportion of congruency level repetitions/alternations (Duthoo & Notebaert, 2012; Jiménez & Méndez, 2013). The idea is always that proportion manipulations render a particular task or attentional set more or less favourable, and proactive regulation is assumed to be at play only when the participant can use this to strategically adapt performance. The proportion manipulation has also been applied across other domains to test for influences of strategic control, for example in multi-sensory integration (e.g., Van den Burg Olivers, Bronkhorst, & Theeuwes, 2008).

In the present study, we first aimed to replicate the findings of Egner et al. (2010), by showing a reduction of the CSE with increasing RSIs in a slightly adapted design (Experiment 1). In a next step, we applied an RSI proportion manipulation to more optimally induce and/or steer proactive regulation, and verified how this manipulation affected the CSEs across the same intervals (Experiment 2). We hypothesized that the RSI manipulation would allow proactive control to be more efficiently and effectively timed, while at the same time enhance the motivation to commit to such. Apart from verifying the presence of a CSE at each interval, we also tested the hypothesis that CSEs decay over time more directly, by analyzing the slope of the CSE development across the four RSIs in both experiments. Whereas a purely *reactive* account of CSEs would predict a similar and negative slope in both experiments, an account that includes *proactive* regulation (affecting CSEs at the longer intervals) would predict the slope to be more negative in Experiment 1 than in Experiment 2.

EXPERIMENT 1

Experiment 1 aimed to replicate Egner et al. (2010)’s findings of a gradual decrease in the congruency sequence effect (CSE) with increasing RSIs, using a slightly modified design. Whereas Egner et al. (2011) varied the RSI in a face-gender Stroop task across 10 levels between 500 and 5000 ms, we restricted the RSI variable to four levels (ranging between 750 and 3000 ms). As the CSE was effectively abolished in the 2500-3000 ms time bin in the study of Egner et al. (2010), we chose not to include longer RSIs. The method and procedure described below closely follow the method section of Egner et al. (2011).

METHOD

Participants**.** A group of 29 Ghent University students (20 females; 9 males; ages 17-25 years) provided written informed consent to participate in the experiment, lasting approximately 45 minutes.

Stimuli and Apparatus. A program written with T-Scope software (Stevens, Lammertyn, Verbruggen, & Vandierendonk, 2006) controlled stimulus presentation and response registration. The stimuli, consisting of the word 'man' (Dutch for 'male') or 'vrouw' (Dutch for 'female') superimposed on a picture of a male or female face, were displayed on a17-inch monitor. The pictures were randomly drawn from a stimulus set comprising 24 black and white pictures (12 of each gender). Each of these pictures could be coupled with a congruent or incongruent gender label that was either printed in upper or lower case (in red Ariel font), resulting in a total of 96 unique stimuli. These gender labels were placed on the centre of the face (approximately at the bridge of the nose) on all 24 individual faces so that the eyes and mouth were not obscured. Stimuli were presented on a grey background. Participants viewed these stimuli at a distance of approximately 60 centimetres. The face stimuli subtended between circa eight and nine visual degrees vertically, and between circa five and six visual degrees horizontally. The gender labels subtended circa two visual degrees vertically, and between circa five and seven vertical degrees horizontally. Responses were detected by means of the 'K' and 'L' keys of a Dell QWERTY keyboard.

Design and Procedure. Participants performed a gender face-word Stroop task (Egner et al. 2008). On each trial they were presented a compound face-word stimulus, consisting of a face with a gender label superimposed onto, and were asked to react to the gender of the face as fast and accurately as possible while ignoring the meaning of the gender label. The relation between the gender label and the face's actual gender could either be congruent (e.g., a male face overlaid with the word 'man') or incongruent (e.g., a male face overlaid with the word 'female'). In response to a female face, participants were asked to press the ‘K’ key with their right index finger, whereas in response to a male face they were supposed to pres the ‘L’ key with their right middle finger. The stimuli remained on screen until a response was recorded. In between two trials, there was a variable interval during which a centrally presented white fixation cross was presented. This response-to-stimulus-interval (RSI) varied between 750, 1500, 2250 and 3000 ms. Participants performed four blocks of 161 trials. In between two blocks, participants were allowed a short, self-paced break. Speed and accuracy were equally stressed. A store coupon was rewarded to the participant who performed best, encouraging participants to respond fast.

For each of the four blocks, the 161 stimuli were presented in pseudo-random sequences that obeyed to some specific constraints. Congruency level and gender of the first trial, which was excluded from the statistical analysis, were randomly selected. Of the remaining 160 stimuli, half were congruent (C) and half incongruent (I). Taking into account the congruency level of the previous trial, each of the four possible sequences (CC, CI, IC, II) was presented with equal probability (e.g., 40 trials in each cell). Furthermore, each of these four cells was equally often paired with each of the four possible RSIs, resulting in equal cell counts across our three-factorial previous congruency (two levels) x current congruency (two levels) x RSI (four levels) repeated-measures design. Over the course of the four blocks of the experiment, this procedure thus amounted to a total number of 40 trials for each sequence-RSI pair. Next, each of the four sequences was equally often paired with a female and a male face target stimulus. These face target stimuli were randomly drawn from the stimulus set on each individual trial, with the restriction that the same face never repeated over successive trials. Moreover, for each successive trial pair, the gender label switched between upper and lower case. These constraints to the random selection ensured that no exact stimulus features were ever repeated on consecutive trials. Finally, each of the cells was on average associated with a 50% chance of response repetition. In sum, following closely the design by Egner et al. (2010), we assured that potential associative influences (e.g., Hommel et al., 2004) on the CSE were balanced out, leaving their impact equal for each cell of interest in our design.

RESULTS

Data Cleaning**.** Mean RTs and error percentages were calculated for each cell of the design. Before entering the statistical analyses, the data were subjected to a trimming procedure. First, extreme RTs[2] (>3000 ms; .1%) as well as the first trial of each block were removed from the analyses, amounting to .7%. Next, we excluded performance errors (2.6%) as well as data points that deviated more than 2 SD from the subject's grand mean RT (4.1%). In analyzing sequential effects, the common procedure is to further eliminate the response following an error trial as well (another 2.3%). Taken together, the RT analysis was thus carried out on the remaining 90.3% of data.

Reaction Times. We ran a repeated-measures ANOVA with the within-subjects factors RSI (four levels: 750 ms, 1500 ms, 2250 ms and 3000 ms), Previous Congruency (two levels: congruent and incongruent) and Current Congruency (two levels, congruent and incongruent) on the mean RTs to verify the impact of the four RSIs on the size of the CSE. In order to correct for violations of sphericity, Huynh-Feldt corrected *p*-values are reported. For the sake of clarity, we report the nonadjusted degrees of freedom for the accompanying *F*-values. Follow-up analyses included planned tests verifying whether the CSE score [calculated with the following formula: (CI-CC)-(II-IC)] significantly deviated from zero for each of the RSI bins separately, as well as planned pair-wise comparisons between CSE scores at different RSI levels. We also calculated the slope of the CSE scores

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[2] Because we did not implement a response deadline, extreme RTs (up to 11.4 seconds) were registered. These nonrepresentative trials disproportionally affected the SDs and thus were first excluded from the analysis.

over these four time bins. A one-sample t-test was carried out to verify whether this slope was significantly different from zero.

The three-way repeated-measures ANOVA revealed a significant main effect of Current Congruency, $F(1, 28) = 67.81$, $p < .001$, evidencing a standard Stroop interference effect: responses to congruent trials (M = 568, SD = 11) were faster than responses to incongruent trials (M = 593, SD = 13). The two-way interaction between Previous and Current Congruency was also significant, $F(1, 28) = 18.14$, $p < .001$, reflecting a standard CSE. As is depicted in the upper left panel of Figure 1, the Stroop interference effect was significantly smaller following incongruent (18 ms) than following congruent trials (33 ms). The significant three-way interaction between RSI, Previous and Current Congruency indicated that the CSE varied in size over the four RSI intervals, $F(3, 84) = 3.37$, $p < .05$. Planned one-sample t-tests indicated that the CSE was significantly different from zero only at the shorter RSIs: a CSE of 24 ms at RSI 750, $t(28) = 3.84$, $p < .01$, and of 26 ms at RSI 1500 ms, $t(28) = 4.41$, $p < .001$. For the two other RSIs, no sign of a CSE was found [$t(28) = .40$, $p = .69$ and $t(28) = .44$, $p = .67$, for RSI 2250 and RSI 3000, respectively]. Pair-wise t-tests between CSE scores showed that the effect was larger at RSI 750 that at RSI 2250, $t(28) = 2.09$, $p < .05$, whereas the difference in CSE between RSI 750 and RSI 2250 was only marginally significant ($t(28) = 1.96$, $p = .060$. The CSE at RSI 1500 was significantly larger than both the CSE at RSI 2250, $t(28) = 2.53$, $p < .05$, and the CSE at RSI 3000, $t(28) = 2.22$, $p < .05$. The variation in the size of the CSE as a function of RSI is visualized in the upper right panel of Figure 1.

To further characterize this variation in the CSE, we calculated the slope of this decrease in CSEs across the four RSI time bins (M = -8.4, SD = 18.0). A one-sampled t-test confirmed that this negative slope was significantly different from zero, $t(28) = 2.48$, $p < .05$.

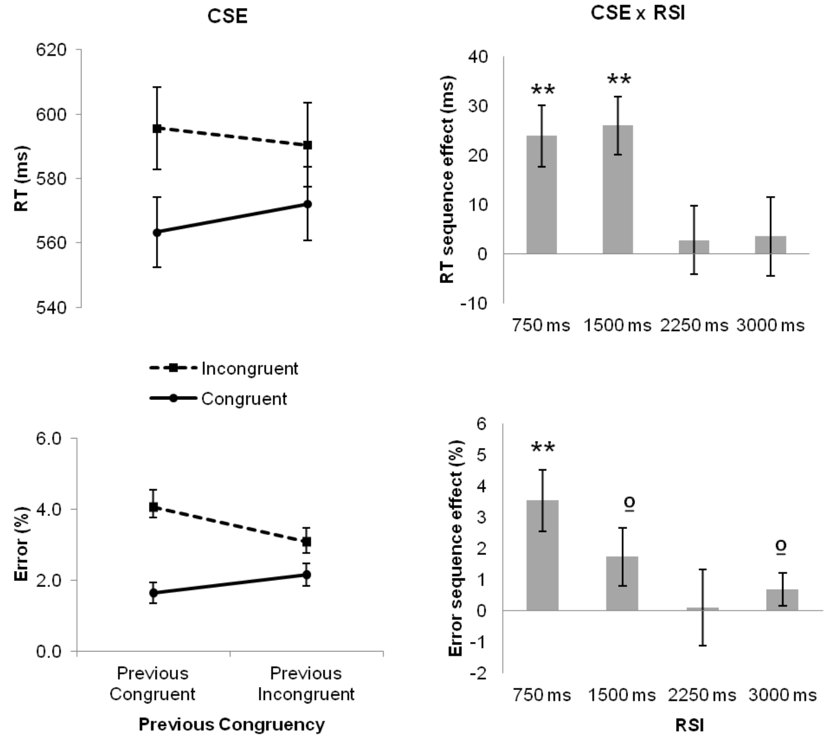

Figure 1: The congruency sequence effect in RTs and errors of Experiment 1. Left: Mean RT data (top) and error percentages (bottom) for incongruent (dashed line) and congruent (solid line) trials, as a function of the congruency level of the previous trial, displaying the classic CSE pattern. Right: The magnitude of the CSE (calculated as [(CI-CC)-(II-IC)]) as a function of RSI. Positive values denote the magnitude of the reduction in RTs (top) or error percentages (bottom) following an incongruent compared to a congruent trial. Error bars reflect the 95% confidence interval around the mean. Note: º = p < .1 / * = p < .05 / ** = p < .01.

Error percentages. Overall accuracy was near ceiling (M = 97.4%, SD = 1.6). In order to test whether error rates followed a similar trend as the reaction time analysis, we ran an identical three-way repeated-measures ANOVA on participants' mean error percentages. The analysis revealed that incongruent trials evoked more erroneous responses (M = 3.4%, SD = 0.4) than congruent trials (M = 1.7%, SD = 0.3), reflected in a significant main effect of Current Congruency, *F*(1, 28) = 30.49, *p* < .001. The two-way interaction between Previous and Current Congruency was also significant, *F*(1, 28) = 8.12, *p* < .05, indicating the presence of a classic CSE. As is depicted in the lower left panel of Figure 1, the difference in error rates between congruent and incongruent trials was significantly smaller following incongruent (.8%) than following congruent trials (2.4%). In line with the RT results, albeit only marginally significant, we found a trend towards a three-way interaction between RSI, Previous Congruency and Current Congruency, *F*(3, 84) = 2.59, *p* = .059, indicating that the size of the error CSE differed between the four different RSIs. One-sample *t*-tests showed that the error CSE was only significant at the shortest RSI interval, *t*(28) = 3.57, *p* < .01, marginally significant at both RSI 1500, *t*(28) = 1.87, *p* = .072, and RSI 3000, *t*(28) = 2.03, *p* = .052, and nonsignificant at RSI 2250, *t*(28) = .07, *p = .94*. Further pair-wise *t*-tests revealed only significant differences in the size of the CSE between RSI 750 and RSI 2250, *t*(28) = 2.33, *p* < .05, as well as between RSI 750 and RSI 3000, *t*(28) = 2.26, *p* < .05. The variation in the size of the error CSE as a function of RSI is visualized in the lower right panel of Figure 1.

To further characterize this pattern, we calculated the slope of the decrease in CSEs across the four RSI time bins (M = -.009, SD =.19). A one-sampled *t*-test confirmed that this negative slope was significantly different from zero, *t*(28) = 2.63, *p* < .05.

DISCUSSION

In Experiment 1, we replicated the main findings of Egner and colleagues (2010), using only a subset of RSIs. Results revealed a classic CSE pattern in both the reaction times and error percentages. Yet, a significant CSE in reaction times was found only at the shortest RSIs (750 ms and 1500 ms), but not at the longer RSIs. Moreover, further analysis revealed that the development of CSEs across the four RSI time bins was characterized by a negative slope. These findings seem to corroborate the view of conflict adaptation as a transient and short-lived enhancement of the attentional set that decays relatively fast with increasing RSI length. Alternatively, participants might have been inclined to ‘just’ rely on reactive control adjustments triggered by previous conflict, as the design did not sufficiently encourage expectation-driven preparatory attentional biasing: because the RSI varied randomly on a trial-by-trial basis, participants could have been discouraged to develop expectations about *when* the stimulus would appear. To put this idea to the test, we introduced a novel RSI proportion manipulation in the otherwise identical design of Experiment 2.

EXPERIMENT 2

In a second experiment we tested the hypothesis that expectation-guided, proactive control will emerge (and produce CSEs at larger intervals) under more favourable conditions. To this end, we manipulated the proportion of the different RSIs in the same gender face-word Stroop task: instead of presenting the stimulus at each RSI with equal probability, we increased the likelihood of stimulus appearance at the longest RSI to 55%, and only a 15% probability of occurrence at the other intervals. We speculated that this manipulation would a) allow proactive control to be timed more efficiently at 3000 ms after the last response (decreasing the overall load of preparation efforts), and/or b) enhance the motivation to implement proactive control at this interval (that falls beyond the range of reactive control) because it is presented more frequently.

Second, we also presented participants one block of Stroop trials with a fixed RSI of 3000 ms, building further on the idea that proactive control benefits from temporal predictability. This extra block was introduced either before or after participants were tested on the mixed RSI blocks (counterbalanced). In case the CSE is purely captured in terms of conflict-triggered, rapidly decaying attentional control adjustments, we expected to find only a CSE at the shortest RSIs in the mixed blocks. If, on the other hand, our RSI proportion manipulation induced strategic attentional control, we expected a CSE pattern at the longer RSIs (either mixed or fixed) as well, in contrast to Experiment 1.

METHOD

Participants. A group of 50 Ghent University students (40 females; 10 males; ages 18-38 years) provided written informed consent to participate in the experiment, lasting approximately 60 minutes. They received an 8 euro participation fee. Due to a misunderstanding of the response mapping instruction (indicated by an excessive error rate), the data of one participant was removed from the analysis. Two participants with error percentages that deviated more than 2 SD from the mean error percentage were also excluded.

Design and Procedure. In this section, only changes to the design and procedure as compared to Experiment 1 are described. Participants performed five blocks of 161 trials. For each of the five blocks, the 161 stimuli were presented in pseudo-random sequences that obeyed to the same specific constraints as described above. Congruency level and gender of the first trial, which was excluded from the statistical analysis, were randomly selected. Of the remaining trials, each of the four possible sequences (CC, CI, IC, II) was again presented with equal probability (e.g., 40 trials in each cell). For one of the five experimental blocks, the RSI was fixed to 3000 ms. In one condition, participants started the experiment with this fixed RSI block (*n* = 22), whereas in the other condition the block with fixed RSI was presented at the end (*n* = 25). For the other four blocks, the proportion of RSIs was manipulated, so that 55% of all trials were associated with the RSI of 3000 ms, whereas RSI 750, RSI 1500 and RSI 2250 were presented with a 15% probability. Over the course of the four blocks, this procedure thus amounted to a total number of 24 trials for all sequence-RSI 750/1500/2250-pairs, and 88 of all sequence-RSI 3000 pairs.

Overall, participants thus performed four blocks of the face-gender Stroop task in a mixed RSI context (750, 1500, 2250 and 3000 ms) as well as one block in a fixed RSI context (3000 ms). Again, a store coupon was rewarded to the participant who performed best

RESULTS

Data Cleaning. The data were again subjected to a trimming procedure. First, extreme RTs[3] (>3000 ms; .04%) as well as the first trial of each block were removed from the analyses, amounting to .7%. Then, we excluded performance errors (4.3%) as well as data points that deviated more than 2 SD from the subject's grand mean RT (3.8%) and post-error trials (another 3.8%). Taken together, the RT analysis was thus carried out on the remaining 87.4% of data.

Reaction Times. We first ran a repeated-measures ANOVA with the within-subjects factors RSI (four levels: 750 ms, 1500 ms, 2250 ms and 3000 ms), Previous Congruency (two levels: congruent and incongruent) and Current Congruency (two levels: congruent and incongruent) as well as the between-subjects factor Order (two levels: fixed RSI first and fixed RSI last) on the mean RTs of the mixed blocks only. The between-subjects variable Order did not interact significantly with any of the within-subjects variables (all *p*s > .21) and is therefore not further discussed below. The ANOVA revealed a significant main effect of Current Congruency, $F(1, 45) = 49.26$, $p < .001$, evidencing a standard Stroop interference effect: responses to congruent trials (M = 530, SD = 10) were faster than responses to incongruent trials (M = 554, SD = 11). The two-way interaction between Previous and Current Congruency was also significant, $F(1, 45) = 16.49$, $p < .001$, reflecting a standard CSE. As is depicted in upper left panel of Figure

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[3] Because we did not implement a response deadline, extreme RTs (up to 7.2 seconds) were registered. These nonrepresentative trials disproportionally affected the SDs and thus were first excluded from the analysis.

2, the Stroop interference effect was significantly smaller following incongruent (15 ms) than following congruent trials (28 ms). In contrast to Experiment 1, the three-way interaction between RSI, Previous and Current Congruency was not significant, F(3, 135) = .30, *p* = .81, indicating that the size of the CSE did not vary significantly over the four RSI intervals. Planned one-sample *t*-tests indicated that the CSE was significantly different from zero at all RSIs: a CSE of 17 ms at RSI 750, *t*(46) = 2.31, *p* < .05, of 12 ms at RSI 1500 ms, *t*(46) = 2.20, *p* < .05, of 15 ms at RSI 2250, *t*(46) = 2.63, *p* < .05, and of 10 ms at RSI 3000, *t*(46) = 2.98, *p* < .01. Further planned comparisons indicated that there were no significant differences in the size of the CSE between any of the two RSIs, all *p*s > .38. The CSEs at the different RSIs are visualized in the upper right panel of Figure 2.

As in Experiment 1, we also calculated the slope of the CSE scores across the four RSI time bins (M = -1.8, SD = 16.5). A one-sampled *t*-test confirmed that this slope was not significantly different from zero, *t*(47) = .74, *p* = .47, indicating that the CSE did not reliably decay over time.

Next, we also ran a repeated measures ANOVA with the within-subjects factor Context (two levels: fixed RSI and mixed RSI), Previous Congruency (two levels: congruent and incongruent) and Current Congruency (two levels: congruent and incongruent) and the between-subjects factor Order (two levels, fixed RSI first and fixed RSI last) on the mean RT of all trials with an RSI of 3000 ms. Again, the between-subjects variable Order did not interact significantly with any of the other variables, all *p*s > .27. Results revealed a significant two-way interaction between Previous and Current Congruency, *F*(1, 45) = 6.88, *p* < .05, reflecting a CSE at the long RSI of 3000 ms, that was not significantly different between the four mixed blocks and the fixed block, *F*(1, 45) < 1, *ns*. However, for the fixed RSI block, the CSE did not reach significance, *t*(46) = 1.03, *p* = .31.

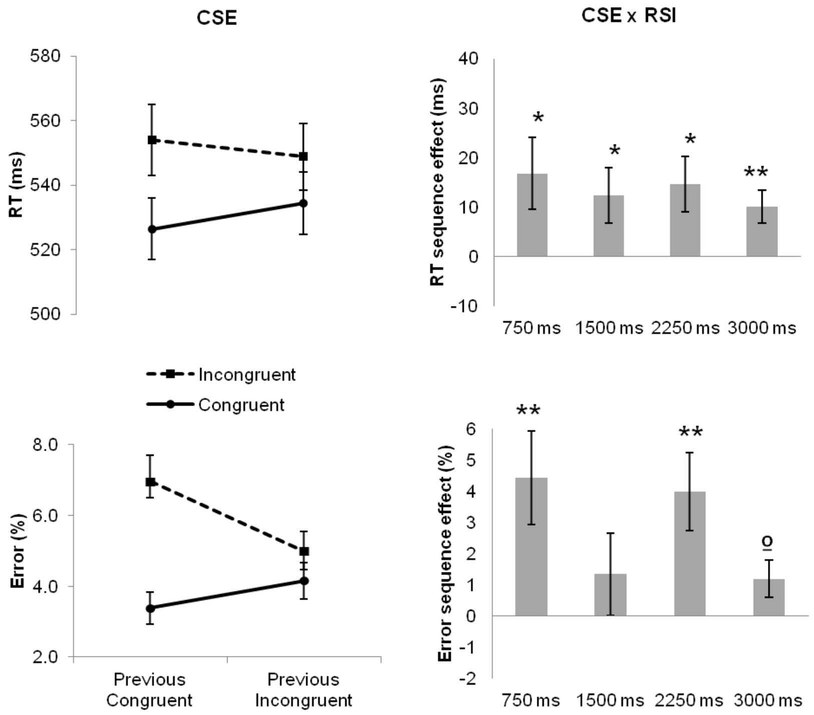

Figure 2: The congruency sequence effect in RTs and errors of Experiment 2. Left: Mean RT data (top) and error percentages (bottom) for incongruent (dashed line) and congruent (solid line) trials, as a function of the congruency level of the previous trial, displaying the classic CSE pattern. Right: The magnitude of the CSE (calculated as [(CI-CC)-(II-IC)]) as a function of RSI. Positive values denote the magnitude of the reduction in RTs (top) or error percentages (bottom) following an incongruent compared to a congruent trial. Error bars reflect the 95% confidence interval around the mean. Note: º = p < .1 / * = p < .05 / ** = p < .01.

Error percentages. Overall accuracy was near ceiling (M = 95.6%, SD = 2.7). In order to test whether error rates followed a similar trend as the reaction time analysis, we ran an identical three-way repeated-measures ANOVA on participants' mean error percentages. The analysis revealed that incongruent trials evoked more erroneous responses (M = 6%, SD = 0.6) than congruent trials (M = 3.8%, SD = 0.4), reflected in a significant main effect of Current Congruency, *F*(1, 46) = 21.18, *p* < .001. The two-way interaction between Previous and Current Congruency was also significant, *F*(1, 46) = 15.15, *p* < .001, indicating the presence of a standard CSE. As is depicted in the lower left panel of Figure 2, the difference in error rates between congruent and incongruent trials was significantly smaller following incongruent (.8%) than following congruent trials (3.6%). The three-way interaction between RSI, Previous Congruency and Current Congruency was marginally significant, *F*(3, 138) = 2.22, *p* = .11. One-sample *t*-tests showed that the CSE was significant at the shortest RSI interval, *t*(46) = 2.96, *p* < .01, at the RSI of 2250 ms, *t*(46) = 3.18, *p* < .01 and marginally significant at the longest RSI interval, *t*(46) = 1.96, *p* = .057. At the RSI of 1500 ms, however, the CSE did not reach significance, *t*(46) = 1.00, *p* = .32.

To further characterize this pattern, we again calculated the slope of the decrease in CSEs across the four RSI time bins (M = -.007, SD =.36). A one-sampled *t*-test confirmed that this slope was not significantly different from zero, *t*(46) = 1.46, *p* = .15.

We also ran a repeated measures ANOVA with the within-subjects factor Context (two levels, fixed RSI and mixed RSI), Previous Congruency (two levels, congruent and incongruent) and Current Congruency (two levels, congruent and incongruent) and the between-subjects factor Order (two levels, fixed RSI first and fixed RSI last) on the mean error rates of all trials with an RSI of 3000 ms. Results revealed that the two-way interaction between Previous and Current Congruency, reflecting a CSE at the long RSI of 3000 ms, was not significant, *F*(1, 45) = 1.84, *p* = .18, nor was it significantly different between the four mixed blocks and the fixed block, *F*(1, 45) = .547, *p* < .47.

Between-experiment comparison. In order to further test our a priori hypothesis that the relative decay of the CSE across increasing RSI time bins would be counteracted by the RSI proportion manipulation – and thus less steep in Experiment 2 than in Experiment 1 - we performed a planned independent-samples *t*-tests on the average slopes of both experiments (-8.4

in Experiment 1 versus -1.8 in Experiment 2). This showed that the difference in slopes between Experiment 1 and 2 was marginally significant, one-tailed $t(74) = 1.63$, $p = .053$. A similar analysis on the slopes of the error CSEs did not produce a significant result, one-tailed $t(74) = .34$, $p = .36$.

DISCUSSION

In Experiment 2, we introduced a novel RSI manipulation to test the hypothesis that increasing the frequency of stimulus appearance at a late interval increased the willingness to employ proactive control in order to cope with the high-frequent conflicting events at longer intervals – which are outside the range of reactive effects. In line with our hypothesis, we found evidence for a significant CSE at RSI 3000 that did not differ from CSEs at earlier intervals– thereby questioning the notion that CSEs solely reflect transient, rapidly decaying reactive control adjustments. In other words, the RSI manipulation seemed to have successfully triggered stronger strategic, top-down control adjustments.

Interestingly, even though not significantly different from the CSE at interval 3000 within the manipulated mixed blocks, the CSE of the fixed 3000 RSI block failed to reach significance by itself. This seems to suggest that temporal predictability is not the only prerequisite for proactive control – the overall effort that accompanies proactive control and the willingness to commit to such effort might be equally crucial. Compared to the blocks of mixed RSI, the block with a fixed and long RSI might have been highly demotivating to the extent that proactive intentions for control faded. This trade-off between costs and benefits should be considered in future research. Further implications are elaborated upon in the general discussion.

GENERAL DISCUSSION

In the current study, we aimed to disentangle influences of proactive and reactive control on congruency sequence effects. Experiment 1 corroborated the findings of Egner et al. (2010), showing that CSEs disappeared at the longer RSIs. This seems to be in favour of the idea that CSEs primarily reflect transient, rapidly decaying *reactive* control adjustments in response to conflict on the previous trial. However, we also demonstrated how *proactive* control can be involved under specific circumstances. Experiment 2, in which participants were steered to expect longer RSIs, showed that CSEs at larger intervals will also become apparent under increased temporal predictability (e.g., Wendt & Kiesel, 2011) and/or motivation to implement control proactively. These results indicate that under favourable conditions, participants can be encouraged to implement control proactively, even in the demotivating context of laboratory experiments.

By raising the probability of the longest RSI to 55%, we obtained robust CSEs at this interval in Experiment 2. It is interesting to note that also at the next-to-longest RSI of 2250 ms, associated with an overall probability of 15%, reliable CSEs were found (in contrast to Experiment 1). This suggests that proactive preparation was already effectuated at this point in time. As CSEs at the two earlier RSIs were significant in Experiment 2 as well, even though participants were primed to expect longer intervals, our findings do, however, indicate that the proactive, expectancy-based effects obtained here complement – rather than overrule – the reactive, short-lived control up-regulations discussed by Egner et al. (2010). Egner and colleagues also touched upon this topic in their discussion, raising the possibility that “short-lived ‘reactive’ CSEs that immediately follow a conflicting event might be ubiquitous, but that the presence of CSEs at longer intervals might be reliant on a different mechanism, such as the ability to maintain an attentional set over time, which may vary more widely across participants as well as between experimental contexts”. Given that intervals employed in many neuroimaging studies are typically relatively long, the present results now pose the intriguing question which underlying control mechanism these studies uncovered.

Interestingly, the present study suggests that proactive control will be more effectively exploited not only when one knows *what* to expect, but also *when* to expect it. Previous research primarily focused on the ‘what’ aspect, by either manipulating the proportion of incongruent trials (Gratton et al., 1992; Logan & Zbrodoff, 1979; 1982; Tzelgov, Henik, & Berger, 1992) or the proportion of congruency level transitions (Duthoo & Notebaert, 2012; Jiménez & Méndez, 2013). Even though the first manipulation was also successful in triggering anticipatory control, as reflected in faster reaction to highly expected incongruent trials than to unexpected congruent trials, future work (see, e.g., Bugg, 2012, for a review) has questioned the role of attentional modulation in these proportion congruent effects (but see Abrahamse, Duthoo, Notebaert, & Risko, 2013; Bugg & Chanani, 2011). The second, more subtle manipulation of congruency level transitions also appeared not strong enough to elicit expectancy-induced, strategic control effects that were clearly dissociable from reactive, conflict-induced adjustments (Duthoo & Notebaert, 2012; Jiménez & Méndez, 2013). The RSI proportion manipulation applied here thus seems a promising tool to further investigate strategic attentional adjustments.

The here reported indications that proactive control can be involved only when rendering circumstances sufficiently favourable, align well with the notion that it is a more effortful procedure than is reactive control. Indeed, it is not so surprising that proactive control does not typically emerge in the enduring and uninspiring circumstances that our participants face while performing our laboratory tasks, with its many highly similar trial repetitions and low reward (punishment) for (sub)optimal performance. A recent study of Locke and Braver (2008) aimed to uncover the underlying mechanisms of how changes in motivational state modulate performance, by implementing reward incentives and probing for individual differences in motivation. Interestingly, they showed that sustained activity in cognitive control regions mediated motivation-induced performance boosts. More specifically, they linked the reward-induced behavioural improvements to participants relying more heavily on a more cognitively effortful proactive control strategy. Even though the specific task design was different, this proactive control strategy also entailed “active maintenance of contextual expectancies during delay periods (and even potentially across trials)" to prevent interference.

Next to intrinsic motivation, we believe that also increased task demands may act as a call for increased effort (Dreisbach & Fischer, 2011; Song & Schwartz, 2008). This might be the reason why we failed to find a significant CSE in the block with a fixed RSI of 3000 ms. Even though this constant RSI allowed for a more precise temporal preparation compared to the mixed RSI blocks, the constant slow pace might have rendered our face-gender Stroop task, which -due to its simple response mapping- already is not the hardest of all conflict paradigms, even less cognitively demanding.

This study primarily served as a first step towards exploring if and under what circumstances proactive control may emerge in interference tasks. The RSI proportion manipulation adopted here can be seen as an effective approach to probe strategic control. Yet, we believe that another crucial aspect may be the willingness of participants to commit to the efforts that accompany proactive control. To further investigate these potential motivational aspects of proactive control, future research could, for example, selectively reward larger RSIs, thereby encouraging participants to prepare and implement control proactively in order to optimize performance on these long intervals.

To conclude, we demonstrated how temporal expectancies can help modulate - and possibly promote a different form of - cognitive control. We suggest that the employment of such a proactive control mode could be dependent on a trade-off between task demands and the effort associated with proactive control. In other words, people seem eager to comfortably rely on the reactive mechanisms they are blessed with, until task demands call for more.

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CHAPTER 7
GENERAL DISCUSSION

There's a mental effect that you get from repetition over time that you can't get any other way.

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- *Steven Drozd of the Flaming Lips.*

INTRODUCTION

Over the last decades, research on cognitive control has witnessed an enormous boost with the formulation of the influential *conflict monitoring theory* (CMT; Botvinick, Braver, Barch, Carter, & Cohen, 2001). The intuitive and powerful feedback loop between conflict detection and resolution (i.e., the conflict-control loop) that lies at the core of CMT has inspired much of the behavioural work on the congruency sequence effect (CSE), the finding of a reduced congruency effects following conflict trials in interference tasks. The CSE seemed to neatly map onto the notion of a conflict-control loop, and soon became a central tool in the study of cognitive control. It has been used not only to inspire, advance and frame further theorizing about cognitive control (Egner, 2007; 2008) but also to garner insights into clinical pathologies as ADHD (Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005), schizophrenia (Carter, MacDonald III, Ross, & Stenger, 2001) and depression (Holmes & Pizzagalli, 2008). Moreover, aided by the rapid emergence of neuroscientific methods in experimental psychology, the theory's clear predictions about the underlying brain structures spawned a vast number of studies aiming to pinpoint the neural markers of conflict detection (e.g., anterior cingulate cortex) and resolution (e.g., dorsolateral prefrontal cortex).

Before the CMT, more descriptive theories of cognitive control (Shiffrin & Schneider, 1977; Norman & Shallice, 1980) ascribed a central role to strategic, voluntary control over attention in aligning our actions with goals or external task demands and overcoming automatic attentional capture. By means of typical tests of selective attention such as the Stroop (Stroop, 1935) and flanker task (Eriksen & Eriksen, 1974), the early studies, for example, explained fluctuations in the size of the congruency effect in response to overall conflict frequency (i.e., to so-called proportion congruency effect) in terms of participants adopting response strategies. More specifically, these studies (Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984; Tzelgov, Henik, & Berger, 1992) suggested that participants exploited the probability of the impending conflict and proactively adjusted to these regularities. Similarly, in the first report on the CSE, Gratton, Coles, and Donchin (1992) put forward the idea that participants applied similar strategic adjustments following congruent/incongruent trials as they would do following congruent/incongruent cues, respectively. The CSE was thus explained by participants adopting either a broad, parallel processing strategy in anticipation of congruent trials, or a more narrow, focused processing strategy in anticipation incongruent trials, based on the implicit expectancy for successive trials with repeating congruency.

As the CMT postulates that adaptive control adjustments occur in reaction to the presence or absence of conflict in the environment, expectancy – and the subsequent shaping of attentional settings (i.e., proactive control) – has since then been overlooked as a potentially critical player in cognitive control. Even though the CMT and related adaptation-by-binding model (Verguts & Notebaert, 2008; 2009) offer an elegant solution to the question about how the cognitive system knows when and where control has to be upregulated in the direct face of conflict, the theoretical plausibility of biasing the cognitive system based on subjective expectancy *before* an upcoming stimulus event, merits further investigation. More than is the case for conflict tasks, research in the task switching domain has reported evidence for such expectancy-driven adjustments in adapting to situational demands (Dreisbach, Haider, & Kluwe, 2002; Dreisbach & Haider, 2006). Therefore, the present thesis reconsidered the role of expectancies as a possible source modulating performance in congruency and task switching paradigms, and set out to investigate how and to what extent expectancies can shape and steer attention and mental flexibility. Interactions between these proactive (expectancy- or prediction-driven) and reactive (conflict- or stimulus-driven) sources of cognitive control were also considered. Before discussing the broader theoretical implications, the empirical work on the interplay between reactive and proactive cognitive control presented in this thesis, is shortly reviewed.

RESEARCH OVERVIEW

In *Chapter 2*, the relative contributions of two possible sources of attentional control underlying the CSE were evaluated (while potential confounding effects of feature integration were optimally controlled for). We created experimental conditions that either favoured or discouraged repetition expectancies: In the repetition condition, we raised the probability of a congruency level repetition to 70%, whereas these repetitions occurred only with a 30% probability in the alternation condition. This allowed us to investigate whether control adjustments were triggered by participants' inherent expectancy for repeating stimulus conditions, or rather merely reflected conflict-induced attentional focussing. Results revealed that the CSE was present in the repetition condition, but not in the alternation condition. Even though this seems suggestive of participants proactively exploiting the global transitional probabilities and prepare accordingly, this difference between conditions disappeared when looking for a transfer of the induced expectancies to a test block, in which repetitions and alternations of the congruency level were equally likely. Moreover, a comparison of trial sequences with a similar conflict history within each of the manipulated conditions revealed that the local context (i.e., recent conflict history) was crucially driving the CSE in the experiment. Overall, then, the study concluded that robust CSEs can be found in the absence of feature integration effects, but that the implicit manipulation of repetition expectancy did not modulate the CSE. In contrast, an interpretation of the CSE in terms of cumulative, reactive, trial-to-trial adjustments best fitted the data pattern.

In *Chapter 3*, a more direct approach was undertaken to investigate a) whether participants in congruency tasks display an inherent bias to expect repeating stimulus conditions, and b) whether such a bias affects the way in which they tackle potential interference from task-irrelevant stimulation. To this end, participants were asked to explicitly produce a prediction about the upcoming congruency level. Over four experiments, it was consistently found that participants indeed display a congruency level repetition bias.

Next, the impact of such repetition expectancy was verified by separately calculating the CSE for repetition and alternation predictions. Interestingly, only following a predicted repetition of the congruency level, a CSE emerged. The CSE was much smaller and mostly absent following alternation predictions. This differential impact of repetition and alternation predictions on performance was explained by assuming interactive effects of reactive and proactive influences, complementing each other following repetition predictions, yet cancelling each other out following alternation predictions. As an alternative explanation, the possibility was raised that participants switched to a neutral control mode (and refrain from preparing) in anticipation of a predicted change in task difficulty, but maintained attentional control settings when predicting a repetition.

Following a similar logic as the experiments described in Chapter 3, *Chapter 4* reported on a task switching study in which participants were asked to explicitly indicate which of the two tasks they expected on the following trial. Irrespective of these expectancies, the colour of the number target signified whether a parity or magnitude judgment had to be performed. Switch probability was varied from 30% over 50% to 70% in three between-subjects conditions. Much like in the Stroop task reported in Chapter 3, participants displayed a clear repetition bias. In all three conditions, task repetitions were significantly over-predicted. Interestingly, this bias was most pronounced in the condition with a high switch probability. Moreover, the study replicated the finding of a reduced switch cost with increasing switch probability (Mayr, 2006; Monsell & Mizon, 2006). In all three conditions, the difference between switch and repeat trials was strongly reduced in anticipation of a task alternation, whereas strong repetition benefits (and/or large switch costs) were found following repetition predictions. These findings suggested an explanation for the reduced switch cost with increased switch probability in terms of increased switch expectancy, and provided further support for prediction-driven control modulations.

In *Chapter 5*, EEG was applied in an attempt to investigate the neural correlates of proactive and reactive control, using a similar prediction Stroop task as in Chapter 3. Behavioural results were replicated. In an attempt to better understand this pattern, we investigated the influence of conflict on the previous trial and prediction type on known EEG markers of Stroop performance. Analysis of the N450 component revealed an influence of predictions on reactive control adjustments: For alternation predictions, the N450 on congruent trials following an incongruent trial was significantly reduced. This suggested that alternation predictions countered or reduced the reactive slowing (e.g., increased control) on IC trials. The conflict slow potential, on the other hand, was not modified by predictions, yet showed to be sensitive only to the congruency level of the previous trial. We also compared the CNV to look for differences in preparation between repetition and alternation predictions. Results suggested that alternation predictions elicited stronger anticipatory activity, and that this difference was more pronounced the stronger participants were biased towards expecting repetitions. This again suggested that participants did not refrain from preparing following alternation predictions. Taken together, these findings suggest an intricate interplay between proactive and reactive control influences.

Finally, *Chapter 6*, focused on the time course of the CSE, building further on an article by Egner, Ely, & Grinband (2010). Here, reactive and proactive control accounts were played out against each other by varying the response-to-stimulus interval (RSI). According to a reactive account, CSEs primarily reflect transient strengthening of the attentional set following conflict. In this light, such account predicts CSEs to steadily diminish over time, whereas a proactive account would assume that the CSE needs some time before expectancies can build up and consequently grow stronger or at least persist over longer time intervals. In a first experiment, it was found that the CSE was indeed abolished at the longer intervals. However, by implementing an RSI proportion manipulation in Experiment 2, significant CSEs were found for these longer intervals. This was taken to suggest that proactive influences on the CSE will emerge under more favourable conditions. Here, the increased temporal predictability might have encouraged participants to deploy proactive control over these longer intervals. Still, as also in Experiment 2 a CSE was found at the shortest intervals, this proactive influence seemed to have complemented (or strengthened) rather than overruled reactive control adjustments.

THE CONGRUENCY SEQUENCE EFFECT: AN UPDATE

Since the majority of the chapters relied on the CSE as a marker to probe both reactive and proactive control adjustments, an update on what the CSE most likely reflects seems appropriate.

CONTROL OR EPISODIC MEMORY?

As thoroughly discussed in *Chapter 2,* a wealth of studies has been dedicated to the purpose of maintaining the CSE as a viable tool to study cognitive control, mostly by controlling for a broad range of possibly confounding episodic memory effects. Most notably, the partial or complete repetition of relevant and irrelevant features may evoke binding effects that critically mimic the pattern of the CSE. Notebaert and Verguts (2007) have suggested a multiple regression approach to statistically segregate influences of feature integration and conflict adaptation. They found that not all of the CSE is due to the binding and unbinding of memory traces. More commonly, though, researchers apply the strategy of expanding the stimulus set and then restrict analysis to a subset of trials with complete alternations (e.g., Kerns et al., 2004; Kunde & Wühr, 2006; Ullsperger, Bylsma, & Botvinick, 2005). However, such strategy leads to both increasingly complex response mappings and a less powerful statistical analysis restricted to a small subset of trials. To counter these shortcomings, we have construed a vocal 8-colour Stroop task that precluded repetitions of relevant and/or irrelevant stimulus features over successive intervals. This procedure allowed increasing the stimulus set while keeping the response mapping intuitive. As has been consistently shown throughout this dissertation, the vocal Stroop task produces reliable CSEs, strongly suggesting a share for cognitive control processes contributing to the effect.

However, the advantage of controlling for feature integration effects in an 8-colour Stroop task also comes at a price, which has received much less attention in this dissertation, and in the literature in general. Much like previous efforts that expanded the stimulus set, all experiments reported in this dissertation kept the rate of congruent/incongruent trials at 50%. With more than two colours, such procedure artificially increases the congruency rate, so that congruent trials occur more often than they would if features are selected randomly (i.e., 12.5% in case of an 8-colour Stroop task). As Mordkoff (2012) has argued, increasing the proportion of congruent trials forces the irrelevant task dimension (i.e., the colour word in the Stroop task) to become informative (see also Dishon-Berkovits & Algom, 2000, as well as Melara & Algom, 2003). As a consequence, participants might have been encouraged to pay more attention to the distractor word.

This has been further explored in the *contingency* account by Schmidt and colleagues (Schmidt, 2013; Schmidt & Besner, 2008). The contingency account relates the CSEs to predictive relationships between stimuli and responses, rather than variation in conflict or biased expectancies. Both Schmidt and De Houwer (2011) and Mordkoff (2012) observed no remaining CSE when all contingencies had been controlled for. As a critical test, the vocal 8-colour Stroop task applied here could be modified to include only a subset of incongruent trials (fixed pairs of colour-word combinations), rendering contingencies for congruent and incongruent trials equal across the experiment, while at the same time controlling for effects of feature integration. If a CSE still emerges, a strong case for a cognitive control account would be made.

In *Chapter 3*, though, behavioural effects found within the 8-colour Stroop task were further verified in a 4- and 2-colour Stroop task. Since all experimental effects were replicated, even in the 2-colour Stroop task where contingencies were similar for congruent and incongruent colours, it can be assumed that contingency learning did not drive all of the effects reported in this thesis.

CONFLICT OR EXPECTANCY?

As feature integration has been consistently controlled for throughout this dissertation, the CSE was interpreted in terms of adjustments in cognitive control. However, the question remained whether these adjustments were (partly) triggered by participants' expectancies (Gratton et al., 1992) rather than (only) by the dominant notion of conflict-induced adjustments to the previous trial (Botvinick et al., 2001). Based on the findings of this dissertation, it can be concluded that he CSE is mainly driven by local, transient reactive control adjustments. In *Chapter 2,* conflict in the local trial history (or absence thereof) determined the reaction time pattern, irrespective of the global expectancies for congruency repetition that were induced by the manipulation. Even in a context where congruency level alternations were highly probable, scarce repetitions of congruent and incongruent trials produced increasingly shorter RTs. Also in *Chapter 6*, where the findings of Egner, Ely, & Grinband (2010) were replicated, it was shown that the CSE diminishes with longer intervals in standard congruency tasks, in line with the transient nature of reactive, short-lived enhancements of the attentional set. Even when participants were manipulated to expect the stimulus to appear at longer intervals, a reliable CSE still emerged at the shortest intervals. In sum, the CSE thus seems to mainly reflect the workings of a cognitive control mechanism that adaptively adjusts performance to comply with task demands in a seemingly automatic fashion, or at least exogenously triggered by previous trial events.

At this point, a recent alternative account proposed by Schlaghecken and Martini (2011) should also be considered. According to this model, the visuo-motor system continuously adapts to the situational demands by tightening or relaxing its responsiveness in a context-dependent fashion, rather than through a conflict detecting and resolving mechanism. The key argument was drawn from a critical review of the literature, suggesting that adjustments following congruent (and thus conflict-free) trials are more frequently and robustly observed. The authors further corroborated their claim in a series of three experiments, suggesting that trial-type repetition benefits were much more pronounced for congruent than incongruent trials, irrespective of expectancies (as similar results were obtained when the proportion of congruent trials was manipulated). Still, *Chapter 2* revealed that reaction times decreased linearly with each consecutive repetition to the same extent for congruent and incongruent trials. Moreover, reactive accounts such as the CMT and the adaptation-by-binding model (Verguts & Notebaert, 2008; 2009) explicitly model such speed-ups in congruent trials following congruent trials, as it is assumed that control is decreased following low-conflict trials.

Therefore, we believe that our and other findings seem to be best captured by the CMT, or by its extension – the adaptation-by-binding account (ABBA; Verguts & Notebaert, 2008; 2009). This latter theory explains the CSE by a strengthening of stimulus-task associations through Hebbian learning in response to cognitive conflict. In this way, the theory bridges the gap between cognitive control and associative learning theories. The model further puts forward noradrenalin as the neuromodulatory force driving the adaptation. However, a study that applied the same vocal 8-colour Stroop task to a group of Parkinson’s disease patients (Duthoo et al., submitted) actually suggested a crucial role for dopamine in bringing about the CSE. More specifically, the study found that PD patients tested off their regular dopamine medication regimen displayed a reliable CSE, that was absent in the same patients tested on medication. An explanation in terms of dopamine overdose seemed to best explain this data pattern. Also van Bochhove, Van der Haegen, Notebaert, & Verguts (2012) suggested a critical role for dopamine in trial-to-trial adaptations to conflict, by showing that blinking (assumed to reflect phasic dopamine bursts) enhanced the CSE. Clearly, these dopamine-driven modulations of the CSE form a challenge for existing theories of cognitive control, and an interesting avenue for further research.

As a final note, the idea of reactive control adjustments has recently been taken one step further. Scherbaum, Fischer, Dshemuchadse, & Goschke (2011) discussed that conflict resolution and subsequent conflict adaptation might not be as clearly separable as initially thought, and proposed that participants can reactively detect and resolve conflict *within* the current trial. These within-trial adaptations are then carried over to the next trial, leading to sequential adjustments in the size of the congruency effect (i.e., a CSE). Within this view, the CSE more clearly reflects *reactive* adaptation to experienced conflict. A similar associative mechanism as present in the ABBA model to explain across-trial adaptation might be able to capture these within-trial adjustments, given a small tweak to the model's architecture. The present dissertation also found some evidence that may seem compatible with the hypothesis that the CSE reflects carry-over effects of within-trial conflict adaptation: In *Chapter 6*, the CSE was found to decay rapidly with increasing RSI, consistent with its supposed transient nature (Egner et al., 2010). However, an RSI manipulation effectively counteracted this decay. This can be interpreted as qualitatively different proactive control processes complementing rapidly decaying reactive control adjustments, or, alternatively, as proactively maintaining these reactive (within-trial) settings at place during the interval. This is further discussed below.

REACTIVE AND PROACTIVE CONTROL REVISITED

In this section, the evidence in favour of reactive and proactive control adjustments, as well as the need for such distinction, is critically discussed. Even though, as noted above, reactive control seems to dominate in CSEs, some indications for the involvement of proactive control can be identified in this thesis. Hence, even though in *Chapter 2* the manipulation of expectancy failed to elicit strong expectancy-driven effects on cognitive control, the following three chapters (3-5) revealed evidence for prediction-driven, preparatory control adjustments by explicitly asking participants to generate predictions. Second, in *Chapter 6* it was shown that under highly favourable conditions, proactive control adjustments might actually arise. However, these proactive influences seemed to complement and interact with reactive adjustments, rather than overruling these, and also seemed much more fragile than their reactive counterpart. In light of these results, how much explanatory power can be ascribed to expectancies? What are the limits of proactive, anticipatory control? And what theoretical implications for research on cognitive control do these findings suggest?

ACTIVE VERSUS PASSIVE EXPECTANCIES

All of the chapters of this dissertation have looked for effects of expectancy on performance and measures of cognitive control. However, expectancy itself is not a unitary phenomenon. It can be shaped by the global probability or immediately preceding stimulus events, triggered by external cues explicitly indicating which event will follow next, or stem from internal, highly subjective sources. These different sources might give rise to expectancies that differ in strength and, consequently, their potency to elicit strong effects on performance. An influential framework by Kahneman and Tversky (1982) proposed that expectancies might vary on a continuum between more active and more passive forms. Passive expectancies are considered more automatic and effortless, while active forms of expectancy ask for more mental resources and draw from our limited attentional capacity.

Jentzsch and Sommer (2002), for instance, applied this distinction on effects of subjective expectancy in simple choice reaction times. The findings of first-level and higher-order repetition and alternation effects in RTs and the P300 component through a build-up of subjective expectancies were related to the passive variant. Matt, Leuthold, & Sommer, 1992 found that instructing participants to expect repetitions or alternations (e.g., an active variant of expectancy) led to strong sequential effects in RTs. Similarly, our manipulation of the global probability of congruency level repetition (*Chapter 2*) or stimulus appearance (*Chapter 6*), on the one hand, might have mainly altered passive expectancies for the more probable event. Still, as participants are becoming more aware of the frequency manipulation, active expectancies might arise as well. In this light, the less subtle RSI manipulation probably was more likely to be picked up by participants, thereby inducing active expectancies to a greater extent than the congruency level manipulation. Explicitly probing participants' predictions, on the other hand, is the clearest example of measuring such active expectancies. Importantly, both forms of expectancy are assumed to work independently of each other, as they might show simultaneous but qualitatively different effects on performance (Jentzsch & Sommer, 2002).

Indeed, the studies in which participants were asked to voluntarily generate predictions clearly produced the strongest effects on performance. The sequential probability manipulation applied in Chapter 2, on the other hand, did not invoke strong enough expectancies to have an impact on performance. This was further corroborated in a study by Jiménez and Méndez (2013). These authors manipulated congruency level transitions in a similar way and found that Stroop performance was not strongly affected by these expectancies. They also measured participants' expectancies in separate blocks and showed that participants' prediction pattern aligned with the transitional manipulation, yet performance in the Stroop blocks showed reaction time patters in opposite directions of expectancies. Here too, expectancies in the Stroop blocks might have not been sufficiently strong to exert a clear impact.

Evidence from the task switching domain further supports the notion that more active expectancies produce stronger effects on performance. Koch (2003) used a fixed and predictable task sequence to look for the effects of subjective, internal expectancies on performance and compared this to performance when additional (redundant) external cues were presented. External cues reduced to switch cost to a greater extent than did internal expectancies. This was taken to reflect stronger preparatory retrieval of task-specific stimulus-response rules in the case of external cues.

Anticipatory processes might sort even stronger effects on attentional and action control if these stem from goals, plans or intentions of the actor, rather than being steered by cues in the environment. In support of this claim, a recent study by Kemper et al. (2013) reported that self-generated, internally triggered predictions exhibited much stronger RT effects (reflected in the LRP, N2 and P300 component) than did external cues. In line with this presumption, work with the voluntary task switching paradigm (Arrington & Logan, 2004; 2005) has shown that task choices that were voluntarily initialized led to smaller switch costs than their cued counterparts. In a similar vein, the self-generated task predictions in *Chapter 4* showed marked performance improvements when predictions were confirmed, and costs when they misfired. In sum, the extent to which expectancies are able to affect performance seems to crucially depend on the exact manipulation. The continuum between passive and active expectancies (Kahneman & Tversky, 1982) captures some of this variance.

THE LIMITS OF EXPECTANCY-BASED PROACTIVE CONTROL

The above discussion of active versus passive forms of expectancy already pointed out that proactive control seems limited to situations eliciting active expectancies. However, even within this scope proactive control has been shown to have limitations.

Conflict Regulation. On a theoretical level, reactive control is assumed to boost the activation of the (attentional) response to the relevant dimension (by strengthening of the stimulus-response connections; Verguts & Notebaert, 2008; 2009) following conflict. Proactive control, in contrast, is hypothesized to involve the flexible and voluntary adjustment of the connections between the relevant and irrelevant stimulus dimensions, on the one hand, and the response on the other hand (see Aarts & Roelofs, 2009). In anticipation of a congruent trial, participants can widen attention, as to allow the irrelevant dimension to contribute more strongly to response selection. When expecting an incongruent trial, participants would, in contrast, focus attention more heavily on the relevant stimulus dimension. Related to this distinction, it was further assumed that reactive control is task- (e.g., Egner, Delano, & Hirsch, 2007; Notebaert & Verguts, 2008) and effector-specific (Braem, Verguts, & Notebaert), whereas proactive preparation can generalize across tasks (Fernandez-Duque & Knight, 2008). In sum, this brief and purely descriptive overview suggests that proactive control is considered a powerful and potentially even more flexible mechanism than is reactive control.

However, the available evidence at present seems to point in the opposite direction. Wühr and Kunde (2008), for instance, showed that the regulation of expected response conflict in a Simon task, in which the irrelevant spatial location of the target interferes with the spatial code of the response, is restricted to strategically responding to the nominally irrelevant location. Cueing benefits for incongruent trials vanished when more than two stimulus locations were involved. In other words, changing the attentional weights for the relevant and irrelevant stimulus dimension (so-called attentional weighting) cannot be proactively applied to reduce expected conflict. Reactive, conflict-induced regulation, on the other hand, has consistently been shown to elicit such enhanced attentional focus to the relevant dimension (e.g., Egner & Hirsch, 2005). Also in *Chapter 2*, it was found that repeated series of incongruent trials produced increasingly fast reactions; even in conditions were global expectancies led participants to expect that such runs of repeated incongruent trials would soon be broken.

The findings of *Chapter 5* also speak to this issue. Here, EEG markers revealed that even though predictions elicited preparatory effects, much of the data pattern seemed to be attributable to reactive control processes. More precisely, focusing attention on the task-relevant stimulus dimension, as reflected in the conflict slow potential component, appeared insensitive to the prediction type. Proactive control was limited to overriding reactively triggered response cautiousness on IC trials following alternation predictions, as reflected in the N450 component, or allowing the word reading process to influence response selection more strongly, reflected in a speeding-up of congruent-congruent transitions following repetition predictions.

A recent study by Rünger, Schwager, & Frensch (2010) also countered the assumption that proactive control would evoke across-task conflict regulation. Over three experiments, the authors failed to find carry-over effects of anticipatory control (in contrast to Fernandez-Duque & Knight, 2008) from one task to the next. However, they raised the question whether one should indeed indentify voluntary adjustments that aim to optimize current task performance with such across-task spill-over effects of control settings. Instead, optimally preparing for a task switch would benefit from not being influenced by a previous task. Yet, to what extent can expectancies help in flexibly switching between two tasks?

Task Switching. The role of endogenous preparation in task switching has been long and fiercely debated. Alternative theories have related the performance improvements associated with increased preparation interval to decay (Allport, Styles, & Hsieh, 1994) or stimulus-compound strategies (Logan & Bundesen, 2003). Nevertheless, a wide range of studies have suggested that preparation effects can be validly measured, and that preparatory processes are not restricted to advance task-set reconfiguration in anticipation of a switch (e.g., Brass & von Cramon, 2002; 2004). Instead, expectancy-driven, preparatory performance benefits have also been found for task repetitions. Dreisbach and colleagues (2002), for example, conducted experiments that varied the local, trial-to-trial probability while keeping the global probability for task switches and repetitions equal. To this end, they presented participants cues that indicated which task (or transition) was most probable on the upcoming trial. They showed that the slowing for unexpected compared to expected task repetitions was equal to the slowing for unexpected compared to expected task switch trials.

In another experiment, Dreisbach and Haider (2006) further investigated preparatory adjustments in the task switching paradigm, by manipulating the global probability of task repetitions (e.g., creating conditions with high versus low switch probability). Participants were either informed in advance about the global probabilities, or were presented with (redundant) probability cues that reflected the global frequencies. It was found that these expectancies about the upcoming difficulty had a significant impact on task processing: in conditions where switch probability was high, RTs for improbable task repetitions were strongly slowed. This effect was strongest with local cues, yet also in the condition where no explicit cue was presented on a trial-by-trial basis, participants were able to use the task probability information to strategically prepare for a switch (or slow down on improbable task repetitions). The fact that preparation effects were not as pronounced in the condition without local probability cues was explained by referring to the failure-to-engage hypothesis (De Jong, 2000), according to which participants do not always engage in effortful advance preparation.

In *Chapter 4*, these findings were further expanded by showing that not only local or global probability cues, but also self-generated expectancies about the upcoming task can strategically influence task switching behaviour. The switch cost was strongly reduced by increasing the switch probability over three between-subjects conditions. This showed that participants adapted to the current task demands, much like in Dreisbach and Haider’s study. However, by selectively probing the task repetition expectancies on a trial-by-trial basis, *Chapter 4* more convincingly showed that this reduction in switch costs in more demanding conditions is related to participants expecting more task alternations, and preparing for this accordingly: Following alternation predictions, the difference between an expected task switch and an unexpected task repetition was abolished.

Still, even in conditions were switches were highly probable, an anticipated task alternation was responded to more slowly than a validly predicted task repetition. This residual switch cost at least suggests that advance preparation for task switches is restricted (e.g., there is a residual switch cost; Meiran, Chorev, & Sapir, 2000; but see Verbruggen, Liefooghe, Vandierendonck, & Demanet, 2007) or that the activation advantage for task repetitions (Dreisbach et al., 2002; or adaptation to task-set, De Baene, Kühn, & Brass, 2012) is not penetrable by preparation. Also in the voluntary task switching domain, voluntarily chosen task alternations produce a reliable switch cost (Arrington & Logan, 2004). This endogenous reconfiguration can be reduced, but not abolished, by increasing preparation time (Liefooghe, Demanet, & Vandierendonck, 2009). In conclusion, preparatory processes clearly play a significant role in task switching, yet the boundaries of this advance preparation suggest that other processes (such as interference or lack of facilitation from the previous trial) cannot easily be overridden.

THEORETICAL AND CONCEPTUAL CONSIDERATIONS

In the present dissertation, the distinction between proactive and reactive conflict regulation was primarily drawn on the basis of expectancy. Reactive conflict regulation is called upon when participants just experienced cognitive conflict, thereby reducing the impact of a next conflicting event. Proactive conflict regulation, in contrast, is recruited when participants are provided with advance information or when they have developed implicit expectancies about the conflict on the upcoming trial (see Aarts & Roelofs, 2009; Fernandez-Duque & Knight, 2008; Rünger et al., 2010; Wühr & Kunde, 2008; for a similar classification). This distinction stresses the anticipatory and voluntary notion of the proactive control processes involved, whereas reactive control was assumed to be activated more automatically, in response to stimuli or conflict. A similar distinction between voluntary control, based on anticipatory information, and reflexive control, triggered by processing stimuli or stimulus features, has been proposed to explain proportion congruency effect at different levels (list-wide versus item-specific; see Bugg & Crump, 2012; Abrahamse, Duthoo, Notebaert, & Risko, 2013).

However, the concepts of ‘proactive’ and ‘reactive control’ have been introduced in a variety of other contexts and theoretical frameworks. Even on a purely conceptual level, the distinction may actually not be as clear-cut as it has been presented (or used as a working hypothesis) throughout this dissertation. In a sense, control adjustments in response to a cue, which were introduced as clear examples of proactive control, can be considered reactive with respect to the cue. Similarly, control adjustments following conflict, which were consistently labelled as reactive throughout this dissertation, can be seen as proactive, considering that these adjustments eventually lead to reduce interference on the next trial. In order to solve this apparent inconsistency, we have opted to refer to the distinction between, on the one hand, prediction-driven or expectancy-based adjustments, and, on the other hand, stimulus-driven or conflict-induced adjustments.

In an overview of the role of the medial frontal cortex in cognitive control, Ridderinkhof, Forstmann, Wylie, Burle & van den Wildenberg (2010) proposed a different taxonomy to differentiate between control processes that collectively aim to optimize performance. *Online* control, in their account, refers to the processes that enable the cognitive system to overcome incorrect or undesirable response tendencies in favour of more controlled, intention-driven response selection. This entails both the selection of the required action based on intentions or task demands and the inhibition of the activation of inappropriate response tendencies. These control processes are considered to operate transiently, and have been introduced in the context of within-trial conflict adaptation in the discussion above (e.g, Scherbaum et al., 2011). Next to online control, Ridderinkhof et al. (2010) suggest a more sustained *anticipatory* regulation of online control, which enables mitigating the undesired effects of unwanted response capture by irrelevant information. Within this anticipatory regulation of control, the authors suggest a further distinction based on crossing two orthogonal dimensions related to (a) the point in time that triggers the control adjustments and (b) the nature of these adjustmens. *Reactive* anticipatory adjustments are made contingent upon internal signals of processing difficulty, such as cognitive conflict or performance errors. *Prospective* anticipatory adjustments depend on explicit cues or instructions to anticipate and guide future processing. These anticipatory adjustments can strengthen online control *proactively*, for instance by modulating inhibition readiness, or they can *pre-empt* the need for such online control, by filtering out task-irrelevant stimuli or stimulus dimensions so that no conflict arises.

When considered in this framework, the present dissertation contrasted prospective and reactive anticipatory regulation of online action control. Reactive anticipatory control was shown to strengthen online control, by selectively enhancing attention to the relevant dimension and/or decreasing the influence of the irrelevant dimension in response selection (e.g., blocking the word reading process). These reactive adjustments can be framed within the conflict-monitoring (Botvinick et al., 2001) or adaptation-by-binding (Verguts & Notebaert, 2008; 2009) accounts. Prospective anticipatory control, in contrast, seemed restricted to modulating these reactive adjustments, either by strengthening/prolonging (*Chapter 6*) or reducing these effects (*Chapters 3* and *5*). Both in the Stroop task studies and in the task switching study, these adjustments were not pre-emptive in nature, as a remaining conflict or switch cost was consistently found.

Finally, it should be briefly mentioned that the distinction between proactive and reactive control is presented in yet another way within the increasingly influential *dual mechanisms of control* framework (Braver, Gray, & Burgess, 2007; Braver, 2012). Within this framework, proactive control is conceptualized as a sustained, effortful and metabolically costly maintenance of goal-relevant information which allows biasing attention, action and perception in a goal-directed manner, before the occurrence of the cognitively demanding event. Reactive control, in contrast, pertains to a ‘late correction’ mechanism, which detects and resolves conflict in a just-in-time manner, after the onset of the high interference event. Proactive control will be more readily utilized when greater or more frequent interference is expected. Reactive control, on the other hand, is necessary to resolve conflict when it is unexpected or infrequent (Burgess & Braver, 2010). Framed like this, proactive control is similar in scope and purpose to the way it was presented in this dissertation, namely to bias attention in anticipation of future events in order to facilitate their processing. Reactive control, on the other hand, is more conceptually similar to what Ridderinkhof and colleagues (2010) have termed online control (see also, Scherbaum et al., 2011). Still, most of the DMC framework has been tested in the field of working memory, using experimental tasks as the recent negatives (Jonides & Nee, 2006) and AX-continuous performance test (Braver, 2012, for an overview), rendering it more difficult to draw clear parallels to empirical findings in the cognitive control and task switching studies reviewed above. One of the key predictions of the DMC framework is that task performance usually reflects striking an optimal balance between proactive and reactive control. In task-switching studies, for example, participants may proactively prepare, based on a cue, for the upcoming task. As this is metabolically costly, participants may sometimes rely on reactive control, and retrieve the appropriate task-set in response to the target, rather than proactively reconfiguring in advance. This seems to be compatible with the failure-to-engage hypothesis by De Jong (2000). Clearly, future research is needed to further explore the explanatory power of the DMC framework in conflict and task-switching studies.

In the next section of this discussion, attention is shifted to the predictions themselves. Should these indeed be considered as an extra measure of proactive control? Do they reveal strategic biases that aim to optimize performance? And to what extent do they also reflect reactive influences?

BIASED EXPECTANCIES

Whenever participants were asked to generate predictions about the upcoming stimulus event, a bias to expect repeating conditions was observed that appeared remarkably consistent and robust across participants, experiments and procedures. Similar biased subjective expectancies have also been suggested to underlie the reaction time benefit for repetition trials in the context of simple 2-choice reaction times (Bertelson & Renkin, 1966; Remington, 1969). When such subjective expectancies were directly assessed, results also typically revealed that the prediction reflected a repetition of the immediately preceding stimulus (Geller & Pitz, 1970; Hale, 1967). In later theorizing, Gratton and colleagues (1992) likewise assumed that participants expect the congruency level (rather than the stimulus itself) of the previous trial to repeat on the next trial. Correspondingly, Dreisbach et al. (2002) also assumed that participants in task switching experiments might implicitly expect a task repetition more than a task switch. Both theoretical assumptions were borne out by the data. Below, the underlying strategy or motivation to succumb to such bias is further explored.

In *Chapter 3*, this repetition bias was framed as a useful, adaptive and strategic tendency to perceive patterns and causality in a random environment. Indeed, looking at real life situations, such overestimation of repeating events does not seem all that counterintuitive: When approaching a busy road intersection in the centre of town, where people tend to cross without much further notice on the traffic passing by, it is usually a good idea to predict that at the next intersection the situation will be similar, and keep the control settings (e.g., more deliberate and careful driving, and a heightened vigilance for unexpected events) at place to cope with the next situation. In other words, there usually is a much higher correlation between successive events than in the random environments created in a controlled laboratory setting. Overpredicting repeating events might thus reflect an adaptive heuristic to confront new situations. As participants were asked to predict the upcoming event as accurately as possible, they were also implicitly encouraged to look for a systematic relationship between successive trial events

However, participants' predictions might be subject to other heuristics and strategies as well (Kahneman & Tversky, 1974). Kareev (1995), for example, showed that people are biased towards repeating the response that was successful on the previous trial when predicting simple stimulus events. In a similar vein, congruency level predictions also seemed to be influenced by the correctness of the prediction on the previous trial. Following a correct prediction, participants displayed a strong repetition bias (ranging between 68% and 80% across the four experiments in *Chapter 3*), whereas following incorrect predictions participants opted for a congruency level repetition and alternation equally often. This corresponds well with neuro-imaging evidence suggesting that people display an inherent tendency to perceive and expect repetition sequences (Huettel, Mack, & McCarthy, 2002), as well as with research on decision-making under uncertainty evidencing a *win-stay/lose-shift* strategy in people's sequence of predictions. Paulus et al. (2001), for example, asked participants to try to predict whether the upcoming stimulus would appear left or right on the screen, and reinforced these predictions randomly. Much like in the experiments reported in this thesis, participants did not know which response would be correct on a given trial. Yet, even with such random reinforcement, Paulus and colleagues also found that participants did not select their responses randomly, but rather seemed to prefer to repeat the response that was correct on the previous trial. Taken together, these findings suggest that in unpredictable environments, like most psychological experiments, people employ strategies to guide their behaviour.

This opens the intriguing possibility that participants' predictions were also, to some extent dependent on performance on the previous trial, and in this respect also reactive. When predictions were successful, a stronger bias to expect repeated stimulus events was found. Still, as participants actually predict congruency level (and not congruency repetition or alternation), this suggests that participants tend to repeat a (correct) response. When predictions misfired, participants might have more carefully considered their prediction, opting for an alternation equally often as a repetition. On average, alternations were predicted more slowly than repetitions (*Chapter 4*) and they also elicited a stronger CNV, especially when participants were strongly biased to expect repetitions (*Chapter 5*). Research with the voluntary task switching paradigm similarly revealed that participants are strongly biased to execute the same task on successive trials (Arrington & Logan, 2004) and that self-generated task alternations elicited a more negative CNV (Vandamme, Szmalec, Liefooghe, & Vandierendonck, 2010). Moreover, reactive, stimulus-driven factors also play an important role in the task repetition bias, as its size is affected by priming due to stimulus repetition (Mayr & Bell, 2006) or previously learned stimulus-task associations (Demanet, Verbruggen, Liefooghe, & Vandierendonck, 2010).

Being biased to expect, predict or execute repetitions of stimulus or task conditions is also reasonable when one assumes that repetitions are easier to perform. Put differently, the cost of incorrectly preparing for an alternation is much higher than the cost for incorrectly preparing for a task repetition (Dreisbach et al., 2002). Further consideration of the efforts and costs associated with proactive, expectancy-based control seems like a promising avenue for further research. Together with some other future possibilities, this is discussed in the final section below.

MERITS, LIMITATIONS AND FUTURE DIRECTIONS

This dissertation's main merit lies in a thorough investigation of the role of expectancies in cognitive control, which hopefully may have deepened our understanding of the nature and limits of proactive cognitive control, and serve as a reference point for further research. Based on the five experimental chapters, the conclusion can be drawn that expectancies, in general, only play a minor role in aligning our behaviour with external task demands, when they are not explicitly manipulated or registered. Usually, the cognitive system can readily rely on less effortful, reactive control adjustments to maintain a sufficient level of performance. In most cases, detecting and resolving cognitive conflicts as they occur may indeed form a more adaptive strategy than proactively preparing for these before they occur. The latter presumably draws more strongly from our limited attention capacity, which consequently cannot be dedicated to other, potentially more rewarding things. Below, some of the further theoretical implications are highlighted, and accompanying suggestions for future research are mentioned.

On a theoretical level, this dissertation firmly grounded the congruency sequence effect as useful tool to investigate (reactive) control, and gave a clear answer to what it most likely does *not* reflect. Future research is needed, though, to further investigate the relative contribution of associative influences (e.g., contingency learning) that have not been controlled for in this dissertation and in the literature in general (Schmidt, 2013). With some additional tweaks in the design, the vocal 8-colour Stroop task that has been applied in many of the empirical chapters might be a promising paradigm to control for both contingencies and feature repetitions. It can also be readily applied to further constrain existing accounts of the CSE. Using this vocal Stroop task, a study on reactive control in Parkinson's disease patients highlighted a crucial role for dopamine in bringing about the CSE (Duthoo et al., submitted), challenging current models of reactive control to integrate this neurotransmitter. Yet, as dopamine has also been implicated to interfere with proactive control and attentional focusing (Aarts, van Holstein, & Cools, 2011), it might also be interesting to investigate the effects of dopaminergic medication on performance in the prediction Stroop task.

As a second theoretical contribution, *Chapter 2* clearly showed that implicit manipulations of expectancies in interference tasks are usually too subtle to elicit strong effects. However, the findings of *Chapter 6* suggested that proactive control may effectively emerge (potentially indirectly, via strengthening of reactive control) under more favourable circumstances. Next to temporal expectancy, another crucial aspect may pertain to the willingness of participants to commit to the efforts that accompany proactive control. A more thorough investigation of these motivational aspects of proactive control may constitute an interesting future line of research. To this end, encouraging participants more strongly to prepare and implement control proactively by means of rewards seems a promising research strategy. To investigate the effect of reward on proactive conflict regulation, one could selectively reward fast responses to correctly predicted incongruent trials in the prediction Stroop task, or the longer RSIs in the variable RSI face-word Stroop task. In a similar vein, the effect of reward on task switching could be probed by selectively rewarding fast reactions to correctly predicted task alternations (but see Nieuwenhuis & Monsell, 2002).

Apart from the willingness to engage in proactive control, also individual differences in processing capacity or working memory might play a crucial role. This could be investigated by relating measures of working memory to participants' ability to exploit the transitional probabilities or task structure (as in *Chapter 2*) in preparing for upcoming difficulty.

On an empirical level, the experimental strategy to probe participants' expectancies more explicitly has proven a fruitful tool to uncover structural biases in predictions and proactive influences on conflict and task-set control. As such, it may also be interesting to apply it to response inhibition paradigms, where the distinction between reactive and proactive stopping has recently attracted considerable research interest (Aron, 2011), and look for preparatory control over stopping inappropriate responses. An extra advantage of this paradigm is that the predictions themselves can be considered as an additional measure to capture 'the elusive homunculus' (Arrington & Logan, 2005) on top of the traditional analysis of RTs and performance errors. However, much like in research with the voluntary task switching paradigm, measures of the prediction or choice bias and subsequent performance rarely seem to correlate, as was also the case in the experiments reported in this dissertation. This suggests that prediction and performance measures 'may index at least partly separable aspects of cognitive control' (Yeung, 2010, p. 361). The lack of robust individual difference correlations might be related to a huge variation in strategies that participants can apply in the prediction task. Better insights in these strategies, or in the contextual manipulations that may influence these, could boost our understanding of prediction-driven control adjustments.

However, one can also question the ecological validity of this manipulation. In everyday life, we are usually not asked to explicitly generate predictions about what is going to happen next. Similarly, inserting these predictions as a second task into a normal Stroop or task switching procedure might have introduced a procedural change that hampers comparison with other research in these paradigms. This also touches upon one question about the role of expectancy in control that remained unresolved in this thesis: to what extent will participants in experimental tasks generate predictions when they are not explicitly asked to. One way of quantifying these sorts of implicit expectancies is by looking for EEG components that are known to be sensitive to expectancy violation (e.g., the P3; Donchin & Coles, 1988; Verleger, 1988; Sommer, Matt, & Leuthold, 1990) and relate these to known markers of conflict control (the N450 and conflict slow potential), without intervening predictions.

In sum, intriguing avenues for further research are plenty. In line with the hot hand fallacy, I predict more nice things to come from these.

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CHAPTER 8
NEDERLANDSTALIGE SAMENVATTING

COGNITIEVE CONTROLE

In onze huidige samenleving worden we dagelijks gebombardeerd door een niet aflatende stroom aan verleidingen waaraan we dienen te weerstaan. Sociale netwerk- en andere entertainmentsites eisen continu onze aandacht op, zelfs tijdens de werkuren, en voor onze favoriete snack hoeven we, bij wijze van spreken, gewoon de hoek om lopen. Hierdoor wordt het meer dan ooit noodzakelijk om ons gedrag en onze aandacht in goeie banen te leiden om aan onze plannen en intenties te voldoen. Norman en Shallice (1980) identificeerden enkele situaties die de noodzaak voor dergelijke cognitieve controleprocessen sterk oproepen, waaronder die situaties waarbij oude, automatische gedragingen dienen overschreven te worden, of nieuwe of nog niet sterk geoefende gedragingen dienen aangeleerd te worden. In dit soort situaties dienen vaak routineuze gedragingen onderdrukt te worden, en de aandacht naar specifieke omgevingsfactoren gericht te worden. Hier kan men zich bijvoorbeeld de eerste autorijles voor de geest halen.

Het nut van dit soort controleprocessen wordt het meest duidelijk wanneer die verstoord worden door neurologische schade. Patiënten met ernstige schade aan de frontale cortex, het hersengebied dat geassocieerd wordt met cognitieve controle, vertonen dan ook duidelijke moeilijkheden met plannen, of met het onderdrukken van routineuze handelingen. Zo kan bij sommige patiënten het zien van een tandenborstel automatisch de handeling ‘tanden poetsen’ oproepen, ook al bevindt die patiënt zich in een situatie waarin het helemaal niet nodig of zelfs niet gepast is om over te gaan tot het poetsen van de tanden (Lhermitte, 1983). Hoewel deze patiëntenstudies interessante inzichten boden in de rol van de prefrontale cortex, focuste het onderzoek rond cognitieve controle zich op het bestuderen van (de neurale correlaten van) aandacht, responsinhibitie en taakafwisseling in gecontroleerde experimenten op gezonde vrijwilligers.

PARADIGMA'S VAN COGNITIEVE CONTROLE

Om de mate waarin mensen weten te weerstaan aan verleidingen of erin slagen routineuze responsen te onderdrukken ten voordele van minder automatische handelingen te onderzoeken, wordt in de experimentele psychologie vaak beroep gedaan op zogeheten conflict- of congruentietaken. In dit soort taken wordt de mate van overlap tussen de relevante stimulusdimensie, de irrelevante stimulusdimensie en de responsdimensie gemanipuleerd om ‘conflict’ te induceren (Kornblum, Hasbroucq, & Osman, 1990). Meest bekende voorbeeld van dit soort taken is de Strooptaak (Stroop, 1935), waarbij proefpersonen gevraagd worden om zo snel mogelijk de kleur van een kleurwoord te benoemen. De overlap tussen de relevante kleurdimensie en de irrelevante woorddimensie wordt gemanipuleerd om tegenstrijdige responstendensen te induceren. Aangezien lezen een sterk automatisch proces is, zijn cognitieve controleprocessen nodig om de taak in overeenkomst met de instructies vlot en juist uit te voeren. Fluctuatie in het verschil in reactietijden en nauwkeurigheid tussen incongruente (vb., ‘ROOD’ in het blauw) en congruente (vb., ‘ROOD’ in het rood) trials – het zogeheten congruentie-effect, werd als maat van cognitieve controle gebruikt doorheen deze thesis.

Waar congruentietaken vooral selectieve aandacht en inhibitie meten, worden *taakafwisselingsparadigma's* aangewend om licht te werpen op hoe mensen flexibel kunnen wisselen tussen cognitieve taken. Hierbij moet de automatische tendens om telkens dezelfde taak te herhalen overwonnen worden (zie Kiesel et al., 2010, voor een review). Wanneer twee of meer verschillende taken dienen uitgevoerd te worden op eenzelfde stimulus, is cognitieve controle nodig om de verschillende taaksets actief te houden en een voorheen toegepaste taakset te inhiberen. Het wisselen tussen twee taken kost tijd, en gaat vaak gepaard met fouten. De *wisselkost*, het verschil in reactietijden en nauwkeurigheid tussen trials waarop proefpersonen dienen te wisselen van taak en trials waarop dezelfde taak herhaald dient te worden, werd als maat van cognitieve controle beschouwd in *Hoofdstuk 4*.

SEQUENTIËLE CONGRUENTIE-EFFECTEN

Zoals hierboven werd aangegeven, worden fluctuaties in de grootte van het congruentie-effect verondersteld aanpassingen in cognitieve controle te weerspiegelen. Het sequentieel congruentie-effect (SCE; ook vaak conflictadaptatie of *Grattoneffect* genoemd), de bevinding dat het congruentie-effect sterk verkleint na een incongruente stimulus, inspireerde een overvloed aan empirisch en theoretisch werk. Dit effect vormt het empirische hart van de invloedrijke conflict-monitoring theorie (CMT; Botvinick, Braver, Barch, Carter, & Cohen, 2001), die de theorievorming rond cognitieve controle sterk domineerde. Deze theorie stelt een regulatie van de aandachtscontrole voorop, waarbij gedrag op een schijnbaar automatische manier wordt gecorrigeerd of geoptimaliseerd aan de omgeving. Binnen dit theoretische kader, wordt het SCE verondersteld een conflictgeïnduceerde vernauwing van de aandachtsfocus te weerspiegelen, die ervoor zorgt dat het gedrag meer in overeenstemming komt met de opgelegde taakinstructies. De CMT stelt dat de verwerkingsstroom continu gemonitord wordt op de aanwezigheid van conflict. Conflict duidt in deze context op incompatibele neurale representaties. In de Strooptaak, bijvoorbeeld, induceert de incompatibiliteit tussen de kleur en de betekenis van een kleurwoord een dergelijk conflict. Na detectie van conflict, waar de anterieure cingulate cortex voor instaat (Jones, Cho, Nystrom, Cohen, & Braver, 2002), wordt cognitieve controle verhoogd, waardoor de impact van een volgend conflict gemilderd wordt.

In dit opzicht, reflecteert het SCE aldus een automatische, *reactieve* adaptatie aan cognitief conflict: na een incongruente trial, wordt de impact van een volgende incongruente trial gereduceerd, weerspiegeld in een kleiner congruentie-effect. Deze dominante interpretatie van het SCE werd in vraag gesteld door de kenmerkintegratietheorie (Hommel, Proctor, & Vu, 2004). Volgens deze theorie reflecteert het SCE geen aanpassingen in cognitieve controle, maar veeleer meer basale episodische geheugenprocessen, waarbij geheugensporen van relevante en irrelevante kenmerken de verwerking van een volgende trial bespoedigen dan wel verhinderen. Een hele reeks studies werd opgezet om het aandeel van cognitieve controle te bepalen wanneer gecontroleerd werd voor allerhande kenmerkherhalingen in de overgang van de ene trial op de andere.

Daarnaast werd een debat gevoerd binnen de notie dat het SCE aandachtscontrole weerspiegeld. De verklaring die oorspronkelijk gegeven werd door Gratton, Coles, & Donchin (1992) deed beroep op strategische aandachtsaanpassingen gebaseerd op de verwachtingen van de proefpersonen omtrent de volgende trial, onafhankelijk van conflict op de vorige trial. Deze auteurs stelden daarnaast de assumptie voorop dat proefpersonen een bias vertonen om gelijkaardige condities te verwachten over verschillende trials heen. Evidentie voor deze verwachtingsverklaring is evenwel schaars. Toch lijkt het intuïtief plausibel dat gedrag en aandacht ook *proactief* gecontroleerd en gestuurd kunnen worden, in plaats van of aanvullend op de reactieve gedragsaanpassingen vooropgesteld door de CMT.

REACTIEVE VERSUS PROACTIEVE COGNITIEVE CONTROLE

Na verloop van tijd en mits enige oefening, lijkt zo goed als alle gedrag moeiteloos en vlot te lopen, schijnbaar zonder veel intentionele controle: Wanneer een spits in volle snelheid op het doel afstormt, hoeft die gelukkig zijn bewegingen niet langer nauwkeurig te plannen. Ook hoeven we tijdens de fietstocht van thuis richting werk niet keer op keer ons hoofd te breken op de te volgen route: zonder veel nadenken gaan we op weg. Totdat plots onverwacht een verstrooide voetganger voor onze fiets opduikt, en we maar nipt op tijd de rem kunnen indrukken. Voor de rest van de trip zullen we geconcentreerder op de omgeving letten, om gelijkaardige situaties te vermijden. Dit soort *reactieve* controleaanpassingen treden vaak snel in actie wanneer het nodig is; ze impliceren een actieve monitor die het gedrag stuurt en aanpast wanneer nodig. Wanneer het licht op rood springt, kunnen we meestal tijdig vertragen. We zijn evenwel ook in staat om actief het groene licht te anticiperen en ons klaar te stomen om sneller dan de omstaande auto’s uit de startblokken te schieten. *Proactieve* controleaanpassingen kunnen aldus ook aangewend worden om onze plannen of intenties te verwezenlijken.

SELECTIEVE AANDACHT

In navolging van de CMT, werd het merendeel van het onderzoek naar selectieve aandachtsmodulatie binnen het reactieve denkkader van conflictadaptatie geplaatst. Niet enkel gedrags-, maar ook EEG- en fMRI-studies werden opgezet om de feedbackloop van conflictdetectie en -resolutie in kaart te brengen. Het model werd verder uitgewerkt met de toevoeging van een neurologisch plausibel stimulus-respons leeralgoritme gedreven door de neurotransmitter noradrenaline (adaptatie-door-binding model; Verguts & Notebaert, 2008; 2009) dat specifieerde hoe het cognitieve systeem weet wanneer en waar controle dient verhoogd te worden.

Desondanks is er ook evidentie voorhanden dat dit soort aandachtsaanpassingen proactief kan worden gestuurd, uitgaand van verwachtingen over of anticipatie op toekomstige gebeurtenissen. Dit soort verwachtingen kan enerzijds impliciet gemanipuleerd worden, door bijvoorbeeld de proportie van congruente/incongruentet trials te verhogen (Logan & Zbrodoff, 1979; 1982; Tzelgov, Henik, & Berger, 1992). In blokken met een verhoogd aantal incongruente trials wordt typisch een gereduceerd congruentie-effect gevonden. Deze adaptatie aan frequent conflict werd geïnterpreteerd als een bewust strategische aanpassing in de controlesettings, gebaseerd op verwachtingen omtrent de probabiliteit van nakend conflict, of de afwezigheid daarvan. Dit soort verwachtingsgebaseerde controle werd evenwel nog vaker onderzocht aan de van cueing paradigma’s, waarbij informatieve cues de proefpersonen alarmeren welke controlesetting meest gepast is voor de daaropvolgende target (Aarts, Roelofs, & van Turennout, 2008; Aarts & Roelofs, 2011; Correa, Rao, & Nobre, 2009; Strack, Kaufmann, Kehrer, Brandt, & Stürmer, 2013). Deze studies toonden overtuigend aan dat cues controleaanpassingen kunnen uitlokken, onafhankelijk van responsconflict. Het blijft evenwel onduidelijk in welke mate dit soort proactieve aanpassingen, net als conflict, de impact van de irrelevante dimensie gradueel kunnen uitfilteren en de focus op de relevante dimensie selectief kunnen verhogen (Aarts & Roelofs, 2011), dan wel beperkt blijven tot het strategisch omkeren van de respons op basis van de irrelevante dimensie (Wühr & Kunde, 2008; Strack, Kaufmann, Kehrer, Brandt, & Stürmer, 2013). In deze thesis werd dan ook onderzocht in welke mate reactieve controle al dan niet een krachtiger mechanisme vormt dan proactieve controle om ons gedrag te optimaliseren.

TAAKAFWISSELING

Meer dan in het onderzoek rond selectieve aandacht, werd het onderzoek naar taakafwisseling getekend door een sterk proactieve component. De robuuste taakwisselkost die gepaard gaat met het wisselen tussen twee of meer cognitieve taken, geeft duidelijk aan dat conflict of interferentie van een voorgaande taak dient opgelost te worden, wil men successvol wisselen naar de andere taak. Wanneer proefpersonen een cue aangeboden krijgen die voorspelt welke taak dient uitgevoerd te worden, wordt de taakwisselkost sterk gereduceerd. Deze bevindingen wijzen erop dat proefpersonen in staat zijn zich proactief voor te bereiden op het wisselen (Koch, 2003) en herhalen (Dreisbach, Haider, & Kluwe, 2002) van taken. Desalniettemin speelt een reactieve component ook een sterke rol in vele taakwisselstudies: stimulusgedreven, associatieve effecten (e.g., binding tussen stimuli en taaksets) dragen bij tot de wisselkost (Waszak, Hommel, & Allport, 2003), en cueing voordelen kunnen deels toegeschreven worden aan het vlugger encoderen van de cue eerder dan het beter voorbereiden op een nieuwe taak (Logan & Bundesen, 2003; maar zie ook Brass & von Cramon, 2004; De Baene & Brass, 2011). Los van deze overwegingen, lijkt de robuuste bevinding van een residuele taakwisselkost aan te geven dat voorbereidende, proactieve processen gelimiteerd zijn (Allport, Styles, & Hsieh, 1994). Verbruggen, Liefooghe, Vandierendonck, & Demanet (2007) toonden evenwel aan dat een complete voorbereiding (en gerelateerde eliminatie van de residuele wisselkost) kan gevonden worden wanneer proefpersonen sterker gedwongen worden tot voorbereiden. Samengenomen, lijken taakwisselingsstudies te suggereren dat anticipatorische controle het cognitieve systeem optimaal kan configureren voor toekomstige gebeurtenissen.

DE ROL VAN VERWACHTINGEN

Zoals de hierboven geschetste korte review liet uitschijnen, berust het gros van de evidentie voor proactieve controle op studies die expliciete cues gebruikten. Hieruit bleek duidelijk dat proefpersonen zich (gedeeltelijk) kunnen voorbereiden op een toekomstig conflict of taakwissel. In welke mate proefpersonen zich laten leiden door verwachtingen wanneer dergelijke cues niet voorhanden zijn, blijft onontgonnen terrein. In deze thesis werd naar methodes gezocht om deze verwachtingen te sturen en in kaart te brengen, alsook hun impact op de verdere verwerking en aandachtscontrole nagegaan. Aan de hand van impliciete en expliciete verwachtingsmanipulaties werden proactieve en reactieve gedrags- en controleaanpassingen tegenover elkaar uitgespeeld.

OVERZICHT VAN DE STUDIES

Naast een algemene inleiding en discussie, werden in deze thesis vijf empirische hoofdstukken gebundeld. Deze hoofdstukken werden als aparte, op zichzelf staande wetenschappelijke papers opgesteld en ter review uitgestuurd. De eerste drie hoofdstukken zijn intussen gepubliceerd. Hoofdstuk 6 zit momenteel verwikkeld in het reviewproces. Het manuscript waarin de EEG-bevindingen uit Hoofdstuk 5 worden gerapporteerd, wordt in de nabije toekomst klaargestoomd om in te zenden.

In *Hoofdstuk 2*, werd een paradigma uitgewerkt dat beter toeliet om het aandeel van cognitieve controle in het sequentieel congruentie-effect (SCE) te evalueren, door te controleren voor alternatieve verklaringen in termen van kenmerkintegratie en facilitatie/interferentie door geheugensporen. Aan de hand van een 8-kleuren, pseudo-gerandomiseerde Strooptaak werden proactieve en reactieve verklaringen voor het SCE tegenover elkaar uitgespeeld. Hiertoe werd de verwachting rond de probabiliteit van opeenvolgende makkelijke/moeilijke trials gemanipuleerd en geverifieerd of dit het SCE al dan niet in de hand werkte. Daarnaast werd nagegaan of de geïnduceerde verwachtingsmanipulatie transfereerde naar een testfase, waarin de sequentiemanipulatie werd weggelaten. De resultaten van twee experimenten lieten zien dat het gedrag sterker bepaald werd door conflict (of de afwezigheid hiervan) in de recente trialhistorie dan door de globale verwachtingen. Dit suggereert dat fluctuerende cognitieve controle in congruentietaken meer gekenmerkt wordt door kortstondige, lokale, reactieve aanpassingen op conflict dan door proactieve, verwachtingsgebaseerde aandachtsmodulatie.

In *Hoofdstuk 3* werd de rol van verwachtingen in aandachtsmodulatie op een meer directe manier getest. Hiertoe werden proefpersonen expliciet gevraagd hun voorspelling omtrent de moeilijkheid van de volgende trial (congruent dan wel incongruent) aan te geven, en de impact van deze predictie op de daaropvolgende prestatie in de Strooptaak werd opgemeten. Het in kaart brengen van de verwachtingen leverde een extra voordeel op: analoog aan studies met het vrijwillige taakafwisselingsparadigma (Arrington & Logan, 2004), kunnen de keuzes van de proefpersonen als een extra meting van cognitieve controle beschouwd worden. Op basis van de theoretische opvattingen van Gratton, Coles, & Donchin (1992) kon voorspeld worden dat proefpersonen algemeen geneigd zijn om repetities van eenzelfde stimulusconditie te verwachten. Wanneer de predicties van de proefpersonen gerelateerd werden aan de gebeurtenis op de voorgaande trial, bleek inderdaad dat proefpersonen een algemene bias tot repetitieverwachting vertonen. Deze repetitiebias had ook een duidelijke impact op een gekende cognitieve-controlemaat: enkel na een repetitiepredictie, vertoonden de proefpersonen een SCE, terwijl dit SCE volledig leek uit te blijven na alternatiepredicties. Deze bevindingen werden verklaard vanuit een interactie tussen conflictgedreven, reactieve controleprocessen en predictiegedreven, proactieve controleprocessen.

In gelijke lijn met Hoofdstuk 3, werd in *Hoofdstuk 4* het effect van expliciete taakpredicties op cognitieve controle nagegaan. De proefpersonen werden gevraagd flexibel te wisselen tussen twee eenvoudige cognitieve taken: ofwel moest het even dan wel oneven zijn van een cijfer beoordeeld worden, ofwel moest dat cijfer geclassificeerd worden als kleiner dan wel groter als vijf. Proefpersonen werden random onderverdeeld in drie condities die verschilden in de mate van effectief aangeboden taakwissels (variërend van 30% over 50% tot 70%). Ongeacht de predictie, bepaalde het kleur waarin het cijfer werd aangeboden welke van de twee taken de proefpersonen dienden uit te voeren. Uit de resultaten bleek dat de predicties van de proefpersonen mee varieerden met de gemanipuleerde probabiliteit van de taakwissels. Opvallend was echter dat in alle condities opnieuw een bias tot repetitieherhaling werd vastgesteld. Bovendien was die het meest uitgesproken in de conditie met de grootste kans op wissels. Daarnaast repliceerde de studie de bevinding van een sterk gereduceerde wisselkost bij een verhoogde kans op wissels (Mayr, 2006; Monsell & Mizon, 2006). Ook werd een mogelijke verklaring voor dit effect gevonden: ongeacht de conditie, bleek het verschil tussen taakwissels en –repetities sterk gereduceerd na een alternatiepredictie. Aangezien proefpersonen meer alternaties verwachtten in de conditie waarin veel gewisseld werd, kan de gereduceerde wisselkost gelinkt worden aan verwachtingen, en proactieve, voorbereidende processen.

In *Hoofdstuk* 5 werd het effect van expliciete congruentievoorspellingen op conflictresolutie in de Strooptaak verder bestudeerd aan de hand van een analyse van het elektro-encefalogram (EEG). Deze techniek tracht de hersenactiviteit die geassocieerd is met een stimulus- of responsconditie in kaart te brengen. Zo kon worden nagegaan hoe zowel verwachtingen als conflict gekende negatieve en positieve deflecties in het signaal moduleren. De contingente negatieve variatie (CNV), een trage golf in het EEG-signaal die gelinkt wordt aan actieve voorbereiding en aandachtscontrole (Brunia, 2004), bleek meer uitgesproken voor incongruente alternatiepredicties. Hieruit kon worden geconcludeerd dat proefpersonen effectief voorbereiden op een alternatietrial. Voorts bleek dat het SCE weerspiegeld werd in een vroege negatieve component van het EEG, de N450. De interactie tussen proactieve, verwachtingsgebaseerde controleprocessen en reactieve, conflictgeïnduceerde controleaanpassingen was aldus gereflecteerd in deze vroege component. Dit lijkt erop te wijzen dat reactief gestuurde woordonderdrukkingsprocessen proactief opgeheven kunen worden, weerspiegeld in snellere reacties op congruente trials na een conflict op de voorgaande trials.

In *Hoofdstuk 6*, ten slotte, werd onderzocht in welke mate proactieve controle baat heeft bij a priori informatie omtrent *wanneer* een stimulus aangeboden wordt, eerder dan welk soort stimulus precies verwacht wordt. Hiertoe werd het respons-stimulus-interval (RSI), de tijd tussen de respons op de voorgaande trial en de stimulus op de volgende trial, gemanipuleerd. Uit voorgaand onderzoek was gebleken dat het SCE sterk uitdoofde naargelang het RSI groter werd (Egner, Ely, & Grinband, 2010). Dit werd geïnterpreteerd als evidentie voor de kortstondige, reactieve aard van dit effect. In een eerste experiment werden de bevindingen van Egner en collega’s gerepliceerd met een beperktere subset aan RSI’s. In een tweede experiment werd de proportie van trials met een langere RSI selectief verhoogd, waardoor proefpersonen geïnduceerd werden de stimulus pas na verloop van tijd te verwachten. Uit de resultaten bleek dat, in tegenstelling tot het vorige experiment, robuuste SCE’s teruggevonden worden op deze latere RSI’s. Dit geeft aan dat proefpersonen wel degelijk proactief cognitieve controle kunnen hoog houden in meer gunstige omstandigheden en/of wanneer de wil om controle hoog te houden vergroot wordt.

BESLUIT

Deze thesis had als doel de rol van verwachtingen in aandachtscontrole grondig onder de loep te nemen. Op basis van de hierboven beschreven studies, kan besloten worden dat verwachtingen slechts een beperkte impact hebben op typische maten van cognitieve controle onder ‘normale’ taakomstandigheden. Wanneer deze verwachtingen niet expliciet gemanipuleerd werden, bleken fluctuaties in cognitieve controle beter gevat door een puur reactief controlemechanisme, dat de aandacht scherper stelde in reactie op recent conflict. Anders gesteld, kunnen we in de meeste gevallen vertrouwen op ons reactief controlesysteem, dat bijstuurt wanneer de nood het hoogst is. Dit lijkt evenwel adaptief, gezien een continue voorbereiding op mogelijke onverwachte gebeurtenissen als erg cognitief inspannend kan geacht worden, en de kracht van dit proactieve systeem duidelijk beperkt is gebleken. Bovendien werd keer op keer vastgesteld dat mensen hun verwachtingen laten leiden door heuristieken. De bias om meer van hetzelfde te verwachten, kan in dit opzicht evenwel ook gezien worden als een adaptieve heuristiek: in het dagelijkste leven is er immers een veel sterkere correlatie tussen opeenvolgende gebeurtenissen dan in de meeste artificiële laboratoriumtaken. Daarnaast bleken expliciete predicties omtrent de moeilijkheid of de gevraagde taak op de volgende trial wel een effect te sorteren op de verwerking. De taakwisselkost werd effectief gereduceerd wanneer hierop geanticipeerd was. Na alternatiepredicties bleek ook de verwerking van een Stroopstimulus meer gecontroleerd. Toch kon ook telkens een reactieve component vastgesteld worden. Dit laat opnieuw zien dat proactieve controle een grotere inspanning vereist, en daarom minder consistent teruggevonden wordt. Manipulaties die dergelijke inspanningen selectief belonen, vormen een interessante piste om proactieve cognitieve controle verder te bestuderen.

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