Control mechanisms in task switching

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Control mechanisms in task switching

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Control mechanisms in task switching

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Doctoral thesis

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To my parents

Contents

CHAPTER 1

Introduction & General Outline

When we drive a car, sometimes there are special signs notifying a change of the direction because of construction work on the main road. Usually we decrease the driving speed because of advanced preparation for executing the expected switch of the direction: we are still driving straight ahead, past the signs, but we have to keep in mind that later we have to turn right (according to the instruction given by the road sign). Therefore, a question arises: are we able to prepare completely for the expected switch, and which are the mechanisms guiding our performance in the preparation for and the execution of this switch?

The present thesis is dealing with this problem: we investigate the ability to prepare for a switch to a new task while still doing an old task. Three main questions are addressed here: 1. What are the control mechanisms underlying the preparation for and the execution of a task switch in a situation with goals overlapping in time? 2. Does the interval between the implementation of a new task and the actual execution of this task modulate the actual task switch? 3. Can preparation for a task switch lead to an effortless switch?

To explore the nature of control underlying the switching between tasks, task switching paradigms are used as an experimental tool.

Task Switching Paradigms

As a point of departure, we introduce the alternating-runs paradigm (Allport, Styles, & Hsieh, 1994; Jersild, 1927; Monsell, 2003; Rogers & Monsell, 1995; Wylie & Allport, 2000). Then we turn to the task-cuing paradigm (Meiran, 1996; Meiran, 2000a; Meiran, Chorev, & Sapir, 2000; Spector & Biederman, 1976; Sudevan & Taylor, 1987) as a corner stone to develop our own paradigm for examining the nature of control in the preparation for and the execution of a task switch.

Alternating Runs Paradigm

In the alternating-runs paradigm (Jersild, 1927), performance on pure-task blocks (participants performing just one task) is compared with performance on mixed-task blocks (participants alternating between two tasks). Performance is usually slower on mixed-task blocks than on pure-task blocks, a difference referred to as shift loss. This shift loss has been attributed to a reconfiguration of a task-set, and thus, to executive control in the mixed blocks.

Many researchers have been using the alternating-runs paradigm. From this research, two main streams in the debate over control processes in task switching have emerged.

Allport et al. (1994) employed the alternating-runs paradigm instructing participants to alternate predictably between two tasks (e.g., color - form - color). The difference in performance between pure blocks and mixed-blocks was referred to as switch costs. These costs were associated with proactive interference from previous stimulus-response mappings, so-called task-set inertia (TSI). Allport et al. showed an asymmetry in switch costs with higher costs for the switch from the more difficult (non-dominant) task to the less difficult (dominant) task than in the reverse direction (see also Wylie & Allport, 2000).

By contrast, Monsell (2003; see also Monsell, Yeung, & Azuma, 2000; Rogers and Monsell, 1995) reported an asymmetry in switch costs in the opposite direction, i.e. with higher costs for the switch from the less difficult task to the more difficult task than in the reverse direction. Monsell and colleagues propose that switch costs should not be taken as an indication of proactive interference, but as a result of consciously initiated task-set reconfiguration (endogenous, goal-directed control[1]). This task-set reconfiguration is completed later by stimulus-driven processing (exogenous control[2]) when the stimulus for the now relevant task is presented. Note that in the paradigm used by Monsell and colleagues, switch costs were measured as the difference in performance on task-switch trials and on task-repetition trials within the same block.

Therefore, from previous research two opposite views arise. In Monsell's terms (e.g., Monsell, 2003; Monsell et al., 2000; Rogers and Monsell, 1995), goal-directed control underlies a task switch. By contrast, in Allport's terms (Allport et al., 1994; Allport & Wylie, 2000; Wylie & Allport, 2000), proactive interference from previous stimulus-response mappings plays a role in a task switch.

It should be noted that the alternating-runs paradigm has one disadvantage: there is no experimental control over the moment in time at which the preparation for an upcoming task starts. This disadvantage is avoided with the task-cuing paradigm.

Task Cuing Paradigm

In the task-cuing paradigm (Meiran, 1996; Meiran, 2000a; Meiran et al., 2000; Spector & Biederman, 1976; Sudevan & Taylor, 1987), a cue is presented either with or right before a given trial, and this cue indicates which task has to be performed at this trial. This method of introducing the upcoming task provides the opportunity to distinguish the passive dissipation of a previous task from the active preparation for an upcoming task. Moreover, by varying the relative duration of the response-cue interval and the cue-stimulus interval it is possible to examine the execution of a task as a function of the time available for dissipation of the previous task and the time available for

[1] In the literature, the terms endogenous, goal-directed, top-down, and executive control are often acknowledged as identical terms. In the present thesis we mention all of these terms citing the relevant literature. However, to avoid confusion, as a main reference term we will use goal-directed control.

[2] In the literature, the terms exogenous, stimulus-driven, and bottom-up control are often acknowledged as identical terms. In the present thesis we mention all of these terms citing the relevant literature. However, to avoid confusion, as a main reference term we will use stimulus-driven control.

preparing the upcoming task. Although many experimenters have been employing the task-cuing paradigm, the nature of control in the preparation for and the execution of a task switch is not yet clear. To shed light on this problem, further research is needed.

Outline

In the present thesis, we propose a new paradigm, the *Overlapping Cues Paradigm (OCP)* as an experimental tool to investigate the nature of control in the preparation for and the execution of a task switch. Our approach provides the opportunity to look separately (a) at the preparation for a new task while still performing an old task, and (b) at the actual switch from the old task to the new task. Thus, we distinguish two aspects of task switching that on the classical task switching paradigms (Allport et al., 1994; Jersild, 1927; Meiran, 1996; Rogers & Monsell, 1995; Spector & Biederman, 1976; Sudevan & Taylor, 1987) take place at one and the same trial, the switch trial.

In the Overlapping Cues Paradigm (see Figure 1.1), two cues are presented within a block of sixteen trials, indicating which of the two tasks has to be performed (in our experiments, either a color or a form match task). Cue1 is presented at the beginning of a block and Cue2 after trial 8. Several trials after Cue2, a star is presented as a warning signal (WS). The two cues are either the same (Cue1 = Cue2, so-called cue non-conflict condition) or different (Cue1 ≠ Cue2, so-called cue conflict condition). Participants are instructed to perform the task indicated by Cue1 until WS and to perform the task indicated by Cue2 after WS. In this way, the WS requires a task switch on cue conflict blocks, but not on cue non-conflict blocks.

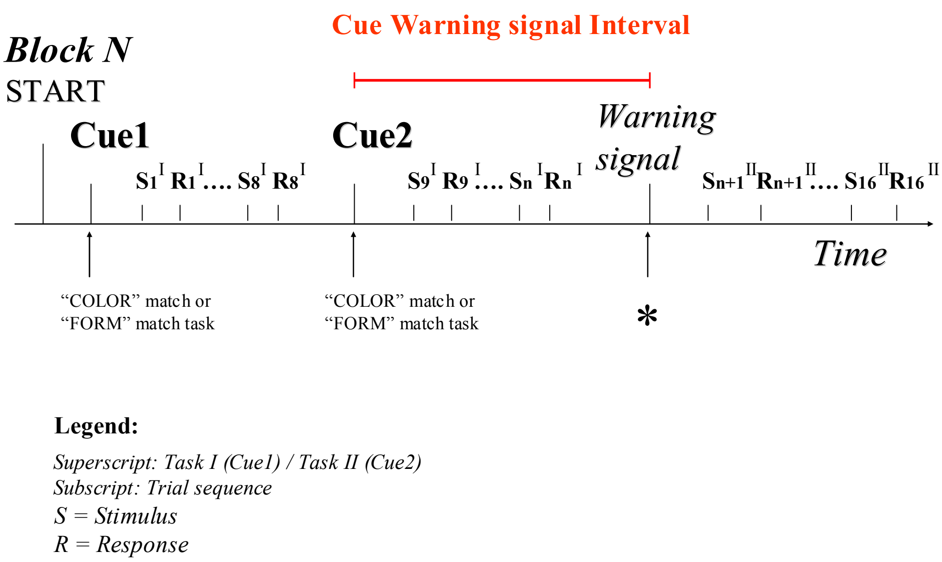

Figure 1.1. A scheme of the Overlapping Cues Paradigm.

One could argue that in OCP we do not have full control over the moment of time in which the preparation for the upcoming task starts. But if you look carefully you realize that OCP introduces a situation in which preparation for a new task is only started at Cue2, because only that is clear whether you have a conflict or a non-conflict block. Put differently, due to the random presentation of conflict and non-conflict blocks you can not predict the type of block and thus you wait until Cue2 before taking any action. Therefore, comparing performance between conflict and non-conflict blocks right after Cue2 (performance difference hereafter referred to as transition costs) will shed light on the nature of control in the preparation for a task switch.

For the moment of the actual task switch, OCP provides the opportunity to look at the performance in two different perspectives. On the one hand, we can compare the performance on the first and the second trial after WS, a performance difference hereafter referred to as switch costs (see also Monsell, 2003; Rogers & Monsell, 1995).

Alternatively, we could compare performance between conflict and non-conflict blocks at the first trial after WS, performance difference hereafter referred to as alternation costs (see also Allport et al., 1994; Meiran et al., 2000). In the present thesis, we only discuss switch costs. We do this for three reasons: (1) to avoid the disadvantage of between blocks comparison in alternating-runs procedure, which implies differences in effort, response criterion, task strategy etc.; (2) because switch costs include components purely related to the actual task switch, while alternation costs do not (e.g., Monsell, 2003; Rogers & Monsell, 1995); and (3) based on the outcomes from some recent studies comparing costs in alternating-runs and explicit task-cuing procedures (e.g., Koch, 2005; Milan, Sanabria, Tornay, & Gonzalez, 2005; Monsell, Sumner, & Waters, 2003; Sumner & Ahmed, 2006; Tornay & Milan, 2001; for an overview see Altmann, 2007). These studies show that switch costs include both the costs of switching tasks and switch-independent costs specific to the first trial of a run.

Obviously, in OCP, the most important part of the block is the interval between Cue2 and WS (Cue2 Warning signal Interval, CWI), and the two trials after the WS. The main line in the present thesis concerns manipulations within this critical region of a block.

Chapter 2 deals with how to distinguish stimulus-driven from goal-directed aspects of control in the preparation for and the execution of a task switch. The two tasks in our experimental case are color and form match. In both tasks, the participants are presented with a colored geometric figure in the upper part of the computer screen and four colored geometric figures in the lower part of the computer screen. In the color match task, participants have to indicate which of the four lower figures has the same color as the upper reference figure by pressing one of four response buttons. In the form match task, they have to indicate which of the lower four figures has the same geometric shape as the reference figure. The relative distance between Cue2 and WS is fixed on two trials. On the trial right after Cue2, hereafter referred to as post-Cue2-trial, the type of the stimulus is manipulated (incongruent vs. congruent). A stimulus is incongruent when the two tasks require different responses (Left panel in Figure 1.2). By contrast, a stimulus is congruent when the two tasks require the same response (Right panel in Figure 1.2). This congruency manipulation on the post-Cue2-trial allows to investigate the potential role of stimulus-driven processes in the preparation for a task switch.

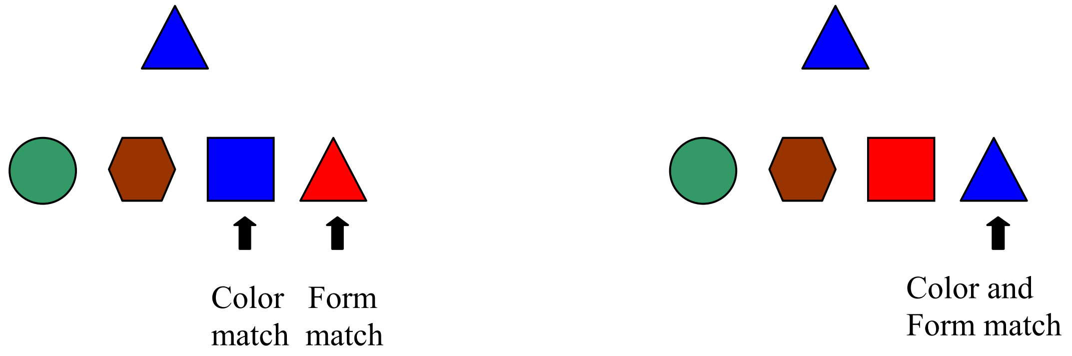

Figure 1.2. Left panel: An example of incongruent stimuli, Right panel: An example of congruent stimuli.

In addition, we manipulate task difficulty with the color match task being easier than the form match task. The effect of task difficulty on the magnitude of switch costs will shed light on the debate over control processes in task switching. More precisely, a potential asymmetry in switch costs should provide evidence on the role of goal-directed control (e.g., Monsell 2003, Monsell et al., 2000; Rogers & Monsell, 1995) versus proactive interference from previous stimulus-response mappings (e.g., Allport et al., 1994; Allport & Wylie, 2000; Wylie & Allport, 2000) in task switching.

In *Chapter 3,* we replicate the experiments from Chapter 2 with only one difference; while in Chapter 2 Cue Presentation Time (CPT) is externally paced, in

Chapter 3, CPT is self-paced (i.e. Cue1, Cue2, and WS are presented in a self-paced mode). The main question addressed here is whether participants can fully anticipate a task switch when they settle the speed for processing this switch by their own rhythm.

C*hapter 4* addresses the question whether and how the interval between Cue2 and WS modulates the preparation for and the execution of a task switch. More specifically, we ask whether switch costs can be eliminated by providing participants with more trials intervening between Cue2 and WS. Within the Overlapping Cues Paradigm, WS appears either after trial 9, 10, 11, or 12. Thus, the number of trials intervening between Cue2 and WS varies: one, two, three, or four trials, respectively. This within-participants manipulation is combined with a manipulation of Cue Presentation Time (i.e. short vs. long externally paced CPT) between participants.

Chapter 5 is concerned with whether and how the combination of goal-directed control and stimulus-driven processing can promote an effortless task switch. The chapter focuses on the question whether stimulus-driven processing at the actual task switch (i.e. a congruent stimulus on the post-WS-trial) reduces switch costs, or perhaps even completely eliminates switch costs.

One could argue that stimulus-driven processing might not only play a role at the actual task switch, but it might also play a role before the actual task switch. Thus, in addition we manipulate the presence of a congruent trial at four different levels: either the post-Cue2 trial (trial 9) is congruent or incongruent, or the second trial after Cue2 (trial 10), or the post-WS trial (trial 11), with all other trials in a block being incongruent. These three types of blocks with a congruent trial are compared to blocks with exclusively incongruent trials. Based on the results from Chapter 4, the distance between Cue2 and WS is fixed on two trials (e.g., WS appears always after trial 10).

Chapter 6 summarizes the results and puts them in a perspective with the existing theoretical accounts in task switching literature.

Chapters 2, 4 and 5 of the present thesis are written as independent papers that have been submitted as journal articles. Therefore some overlap between the chapters (in the introduction, the method sections, and the general discussion) was unavoidable. To minimize this overlap, all references for the whole thesis are given in one reference list at the end of the thesis.

CHAPTER 2

Control mechanisms in task switching[1]

Abstract

The Overlapping Cues Paradigm (OCP) was introduced to investigate the control mechanisms in task switching. Two cues indicated whether participants had to perform a color or a form match task. Within each block of 16 trials, Cue1 was presented before trial 1 and Cue2 after trial 8. In non-conflict blocks, both cues were identical while in conflict blocks, the two cues differed. Two trials after Cue2, a signal forced a task switch in conflict blocks, but not in non-conflict blocks. On the trial right after Cue2 (post-Cue2-tial), the stimulus congruency (congruent or incongruent) was manipulated.

The results show: (1) Less costs for preparing the switch from the more difficult to the easier task than in the opposite direction, when the post-Cue2-trial was incongruent. (2) Higher costs for the actual switch from the more difficult to the easier task than in the opposite direction, when the post-Cue2-trial was congruent. These results provide evidence that both a consciously initiated task-set reconfiguration as proposed by Monsell and colleagues (e.g., Monsell, 2003; Rogers & Monsell, 1995) and the active disengagement of the previous task, task-set inertia as proposed by Allport and colleagues (e.g., Allport, Styles, and Hsieh, 1994; Wylie & Allport, 2000), play a role in task switching.

[1] This chapter is identical to Bialkova, S. (in revision-a). Control mechanisms in task switching.

Introduction

A large body of literature has addressed the control mechanisms in task switching, in a situation where the preparation for and the actual execution of a task switch take place at the same position in a sequence of trials (Allport, Styles, and Hsieh, 1994; Jersild, 1927; Meiran, 1996; Rogers & Monsell, 1995). However, in real life this is not the only scenario of task switching. Rather, we often start the preparation for a new Task B (i.e. we implement the goals associated with Task B) while still performing Task A. Thus, the preparation for Task B overlaps with the execution of Task A. The present study provides an experimental investigation of task switching in such a situation where different task goals overlap in time. More specifically, we are interested in how the implementation of a "new" Task B affects the concurrent execution of an "old" Task A, and whether and how the implementation of Task B affects performance on Task B at the moment at which Task B has actually to be performed. Thus, the central question concerns the control mechanisms underlying the preparation for and the execution of a task switch in a situation with goals overlapping in time. To address this question, we introduce the Overlapping Cues Paradigm (OCP).

In the following we will first discuss general concepts and theories of task switching and then turn to the OCP.

Task Switching Paradigms

People are capable to switch rapidly from one task to another in their everyday life. Usually, task switching goes with some time costs and errors known as switch costs (SCs). Jersild (1927) was one of the pioneers investigating the nature of switch costs by comparing the speed and accuracy of task performance on pure-task blocks (participants performing just one task) with mixed-task blocks (participants alternating between two tasks). The difference between performance on pure- and mixed-task blocks was called "shift loss", a cost that was attributed to a reconfiguration of task-set in the mixed blocks.

Allport, Styles, and Hsieh (1994) used Jersild's paradigm, with prespecifying the task sequence (e.g., color - form - color). Based on their research, Allport and colleagues suggested that switch costs should not be taken as a result of executive control operations, but as an index of poststimulus interference by a recently adopted task-set. They called this effect task-set inertia (TSI). Varying the response stimulus interval (RSI), Allport et al. showed that switch costs are reduced with longer RSI. However, they did not find a complete elimination of switch costs even when the RSI had a duration of more than a second. They explained this finding by assuming that the active disengagement from the previous task-set depends on the appearance of the next stimulus, and thus, leads to residual switch costs. As further support to the TSI account, Allport et al. (see also Wylie & Allport, 2000) demonstrated an asymmetry in switch costs, with higher costs for the switch from the non-dominant (more difficult) to the dominant (less difficult) task than for the opposite direction.

In contrast, less costs for the switch from the non-dominant to the dominant task have been reported by other researchers (Monsell, 2003; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001) using a paradigm in which participants alternate predictably between two tasks. In this paradigm, switch costs are quantified by comparing the performance on task-switch trials with the performance on task-repetition trials within the same block of trials. The switch costs were attributed to a consciously initiated task-set reconfiguration (endogenous, goal-directed control). This task-set reconfiguration is completed later by stimulus-driven processing (exogenous control) when the stimulus for the now relevant task is presented.

In the paradigms discussed so far, the moment of a task switch is known in advance and participants can start to prepare the switch at any trial preceding the actual switch. Thus, there is no control over the moment at which the preparation for a new upcoming task starts. This problem is avoided in the task-cuing paradigm (Meiran, 1996, 2000a; Meiran, Chorev, & Sapir, 2000; Spector & Biederman, 1976; Sudevan & Taylor, 1987). In this paradigm, the task to be performed at a given trial is indicated by a cue that is presented either with or right before the trial. By varying the duration of the response-cue interval and the cue-stimulus interval, it is possible to distinguish the passive dissipation of a previous task from the active preparation for an upcoming task. Meiran et al. (2000) argued that on switch trials a reconfiguration takes place and that this reconfiguration has to be distinguished from the preparation that takes place on non-switch trials (see also Luria & Meiran, 2003; Rubin & Meiran, 2005; Yehene, Meiran, & Soroker, 2005).

Recently, other researchers also tried to separate the preparation for a task switch from the execution of a task switch (e.g., Gopher, Armony, & Greenshpan, 2000; Kleinsorge & Gajewski, 2006; see also Sohn & Anderson, 2001; Sohn & Carlson, 2000 for studies investigating the preparation for a task switch with and without foreknowledge). Kleinsorge and Gajewski (2006) studied the preparation for a task switch in a paradigm in which trials were presented in a pair of two. Each pair was preceded by a precue. The precue provided information for the task that has to be performed on the second trial of the pair, but did not provide information for the task that has to be performed on the first trial of the pair. For the first trial, the stimulus itself contained information about the task that has to be performed on the current trial. The authors reported that preparation for the second trial takes place during the encoding of the precue.

In the paradigm introduced by Gopher et al. (2000), participants were instructed either at the beginning of a two-part block or prior to each part of a block which task has to be performed. A reduction of the first-trial costs was obtained with advance preparation (i.e. on the first trial of a block, participants were faster when the instruction was given at the beginning of a two-part block than prior to each part of a block). This finding was accounted for in terms of “activation and execution of control strategies” (Gopher et al., 2000, p. 308). By contrast, other researchers (e.g., Logan, 2003, 2004; Logan & Bundesen, 2003, 2004) suggested that explicit task cuing procedures do not require endogenous control.

In sum, the results from the previous studies do not provide clear evidence on whether and how different control mechanisms affect the preparation for a new upcoming task. In the present study, we propose a new paradigm, the Overlapping Cues Paradigm, as an experimental tool to investigate the control mechanisms involved in the preparation for and the execution of a task switch. In the next section, we provide a general outline of the Overlapping Cues Paradigm.

The Overlapping Cues Paradigm (OCP)

The general idea behind OCP is as follows. We provide participants with information about a new task-set while they are still required to perform the old task for a number of trials. Only after having performed the old task for some trials, participants receive a warning signal which indicates that they now have to switch to the new task. This approach allows us to look separately at (a) the preparation for a new task while still performing the old task, and (b) the actual switch from the old task to the new task.

In the present paradigm two cues (Cue1 for Task1 and Cue2 for Task2) are presented within a block of 16 trials (see Figure 2.1). The two cues are the words Color or Form indicating that either a color or a form match task has to be performed. In both tasks, the participants are presented with a colored geometric figure in the upper part of the computer screen and four colored geometric figures in the lower part of the computer screen. In the color match task, participants have to indicate which of the four lower figures has the same color as the upper reference figure by pressing one of four response buttons. In the form match task, they have to indicate which of the lower four figures has the same geometric shape as the reference figure. These two tasks were expected to differ in their overall difficulty, with the form match task being more difficult than the color match task. To anticipate, this turned out to be the case.

The beginning of a block is indicated by the word Start. Then Cue1 appears, followed by a series of 8 trials. After the response on trial 8, a second cue, Cue2, appears. Cue2 is either different from Cue1 (Cue2 ≠ Cue1; cue conflict condition) or the same as Cue1 (Cue2 = Cue1; cue non-conflict condition). Note that participants are instructed to continue after Cue2 with the task indicated by Cue1. Two trials after Cue2 (i.e. after trial 10), a star is presented as a Warning Signal (WS), which indicates that participants now have to perform the task indicated by Cue2. The WS thus requires a task switch in (cue) conflict blocks but not in (cue) non-conflict blocks (for short, in the following, we use the terms conflict blocks and non-conflict blocks).

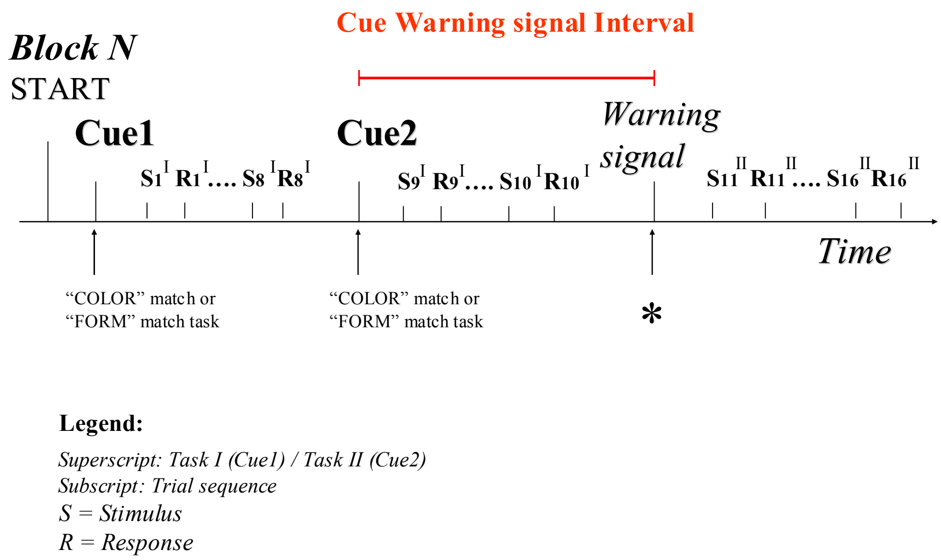

Figure 2.1. A scheme of the Overlapping Cues Paradigm.

One could argue that in OCP there is no full control over the moment of time in which the preparation for the upcoming task starts. However, by presenting conflict and non-conflict blocks in an unpredictable random order the OCP induces a situation in which preparation for a new task can only be started at Cue2, because only then it becomes evident whether the block is a conflict block or a non-conflict block.

Therefore, the most important part of a block is the interval from Cue2 to the Warning signal (Cue Warning signal Interval, CWI) and the two trials following WS. In the following, we zoom in into this critical region of a block.

The first central question is: what do participants do when Cue2 appears? One possibility is that participants simply encode the intention to switch at some later point in time, without any further preparation for the actual task switch (which takes place after the warning signal). Alternatively participants might at least partially implement the second task at Cue2 on an abstract goal level despite the fact that they will still have to continue with the first task for a couple of trials.

To test these scenarios we will have a look at the performance right after Cue2. On the trial right after Cue2 (hereafter referred to as post-Cue2-trial), we will compare performance on conflict and non-conflict blocks, a difference hereafter referred to as transition costs. The transition costs will provide an estimate of control mechanisms involved in the preparation for an upcoming new task while still doing an old task. Note that on the post-Cue2-trial, for both, conflict and non-conflict blocks, participants have to do the task indicated by Cue1. Thus, if Cue2 is only picked up as an advance indicator of a task switch, potential transition costs should appear irrespective of task difficulty. By contrast, if participants do implement the task indicated by Cue2, we might expect an asymmetry in transition costs (easy color match task versus more difficult form match task).

However, one could argue that transition costs could be unaffected by task difficulty, even if the second task is being implemented at Cue2. This could be the case when participants have enough time at Cue2 to reconfigure and prepare in advance for the upcoming task such that processes triggered by Cue2 are completed before the post-Cue2-trial is presented. To test this possibility we will manipulate the Cue Presentation Time between experiments (short externally paced (200 ms) and long externally paced (900 ms), in Experiments 1 and 2, respectively).

In addition, we vary stimulus congruency at the post-Cue2-trial: incongruent (when the two tasks require different responses, Left panel in Figure 2.2) vs. congruent (when the two tasks require the same response, Right panel in Figure 2.2).

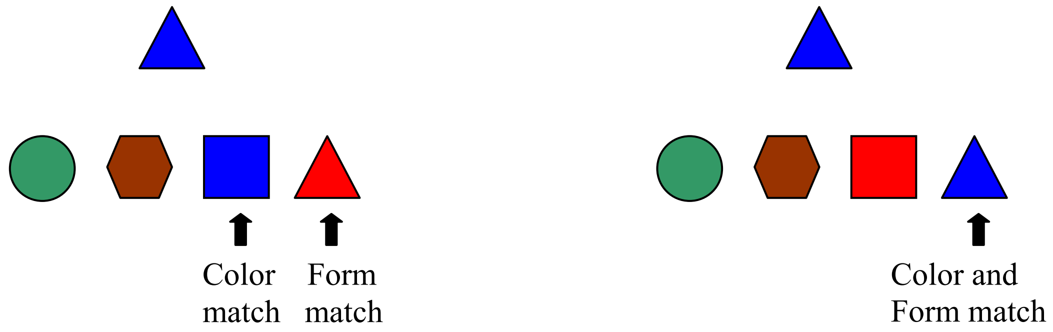

Figure 2.2. Left panel: An example of incongruent stimuli, Right panel: An example of congruent stimuli.

In contrast to this manipulation, previous studies manipulated stimulus in/congruency primarily at the switch trial itself (e.g., see Goschke, 2000; Hunt & Klein, 2002; Kleinsorge & Gajewski, 2006; Koch & Allport, 2006; Meiran, 2000b; Rogers & Monsell, 1995; Ruthruff, Remington, & Johnston, 2001; Wylie & Allport, 2000; Yeung & Monsell, 2003). In another study from our lab (see Chapter 5) aiming to explore whether the combination of goal-directed and stimulus-driven processes could favor an effortless switch, we also manipulated the position at which a congruent stimulus appeared.

In the present Chapter2, the manipulation of stimulus in/congruency at the post-Cue2-trial aims at exploring the implementation of the second task in more detail. Thus, if on conflict blocks the second task is implemented on an abstract goal level, stimulus congruency on the post-Cue2-trial should not matter for transition costs. By contrast, if the second task is implemented at the level of implicit responding, incongruent trials should show higher transition costs than congruent trials, because the incongruent trials should trigger two competing response tendencies for the post-Cue2-trial.

The second main issue concerns the actual task switch. For the moment of the actual task switch, the OCP provides the opportunity to look at the performance in two different perspectives. The first one compares performance on the first and on the second trial after WS, a difference hereafter referred to as switch costs. This way of measuring switch costs is based on Rogers and Monsell‘s finding of a sharp improvement in performance between the switch trial and the next trial of a run (e.g., the first and the second trial of a run of four trials), but no further improvement in performance over the three trials following the actual switch trial (Rogers and Monsell, 1995; see also Monsell, 2003). Alternatively, we could compare performance on conflict and non-conflict blocks on the first trial after WS, i.e. in terms of alternation costs (see also Allport et al., 1994; Meiran et al., 2000).

In the present study, we discuss the data only in terms of switch costs. We will test whether and how switch costs depend on the type of the actual task performed (switch to the easier color task vs. switch to the more difficult form task), on stimulus congruency on the post-Cue2-trial (congruent vs. incongruent), and on Cue Presentation Time (short vs. long externally paced).

Our choice to discuss data only in terms of switch costs is determined by the following reasons: (1) to avoid the disadvantage of between blocks comparisons in the alternating-runs procedure which implies difference in effort, response criterion, task strategy etc.; (2) because switch costs include components purely related to the actual task switch, while alternation costs do not (e.g., Monsell, 2003; Rogers & Monsell, 1995); and (3) based on the outcomes from some recent studies showing that switch costs include both the costs of switching tasks and switch-independent costs specific to the first trial of a run (e.g., Koch, 2005; Milan, Sanabria, Tornay, & Gonzalez, 2005; Monsell, Sumner, & Waters, 2003; Sumner & Ahmed, 2006; Tornay & Milan, 2001; for a review see Altmann, 2007).

Finally, with the OCP we can also compare performance on the first and on the second post-WS-trial on non-conflict blocks, a difference hereafter referred to as restart costs (i.e. performance costs that are associated with continuation of the same task after an interruption; see also Allport & Wylie, 2000; Gopher et al., 2000; Monsell, 2003).

Experiment 1

In Experiment 1, the time for presenting Cue1, Cue2, and the warning signal was set to 200 ms. In this situation, participants have little time to implement a second task at Cue2, and to prepare the actual task switch that occurs right after the warning signal.

Method

Participants

Twenty participants, 13 women and 7 men, between the ages of 18 and 35 years took part in Experiment 1. All had normal or corrected-to-normal vision.

Materials

Stimuli consisted of a reference figure and four match-figures (see Figure 2.2). The reference figure was displayed in the upper half of the screen while simultaneously the four match-figures were displayed in the lower half of the screen. All stimuli were selected from a collection of four different geometric figures (square, triangle, circle, and hexagon), which were filled with one of four different colors (red, blue, green, and brown).

The combinations of form, color, and position of the figures were generated randomly. Each combination appeared only once during the experiment. For half of the stimuli presented on the post-Cue2-trial, the reference figure and the correct match figure had both the same color and the same form, yielding a congruent stimulus. The other half of the stimuli on the post-Cue2-trial were incongruent. All other trials were also incongruent.

Design

The experiment consisted of 64 blocks of 16 trials. There were 8 experimental conditions resulting from the full crossing of three within-participants factors: Cue1 with levels Color and Form, Cue2 with levels Color and Form, and Stimulus congruency on the post-Cue2-trial with levels Congruent and Incongruent. Each of the 8 conditions was realized by 8 blocks. Presentation order of the 64 blocks was random.

Before the experiment there was a short practice session consisting of 6 practice blocks. These blocks were excluded from the data analysis.

Procedure

Each block began with the word “START”, followed by Cue1. Cue1 was the Dutch word “VORM” (“FORM”) for matching based on form, or the Dutch word “KLEUR” (“COLOR”) for matching based on color. Cue Presentation Time for Cue1 (as well as for Cue2 and WS) was 200 ms. One hundred milliseconds after Cue1, a series of 8 trials appeared on the computer screen for which the participant had to perform the task indicated by Cue1. The interval from response to trial n to onset of the stimulus for trial n+1 was 100 ms. Two hundred milliseconds after the response on trial 8 a new cue, Cue2 appeared for 200 ms. One hundred milliseconds after Cue2, trials 9 and 10 appeared, for which participants were instructed to keep performing the task indicated by Cue1, but to remember the second cue. Two hundred milliseconds after the response on trial 10 a visual warning signal (star) was presented for 200 ms. One hundred milliseconds after the warning signal, trials 11 to 16 were presented, for which participants were instructed to perform the task indicated by Cue2. After the last response of the block (i.e. response to trial 16) a new block started with the word “START” displayed on the screen.

Participants were asked to respond as fast and as accurately as possible with two fingers (index and middle finger) of each hand on a button box with four buttons, which were used to indicate the location of the correct match figure. Feedback asking for faster responding was given if participants did not respond within 2000 ms.

Results

For all 16 trials of each block, reaction time (RT) was recorded, as were incorrect responses and out- of- time- responses (trials with RT longer than 2000 ms).

Reaction times:

RTs for trials 1 to 8 were submitted to an analysis of variance with the factors Cue1 (Color or Form), Cue2 (Color or Form), Stimulus congruency on the post-Cue2-trial (Congruent or Incongruent), and Trial position (1 to 8). Participants were faster in performing the color match task than the form match task, resulting in a significant main effect of Cue1, $F(1, 19) = 295$, $p < .0001$. The reliable main effect of Trial position, $F(7, 133) = 9.7$, $p < .0001$, was due to slower performance on the first trial of a block than on trials 2 to 8. No other main effects or interactions reached significance. This is in line with what one would expect, because only Cue1 is a real experimental factor for these trial positions while all other factors (except trial position) are in fact dummy factors; they only can start to play a role in the critical region of a block between trials 8 and 12.

A similar pattern was obtained for trials 13 to 16. In the corresponding ANOVA, the significant main effect of Cue2, $F(1, 19) = 193$, $p < .0001$, revealed faster performance on the color match task than on the form match task. The two-way interaction Cue1 by Cue2 was also reliable, $F(1, 19) = 18$, $p < .0001$. This reflected faster performance if Cue2 was the same as Cue1 than when it was different. None of the other main effects or interactions were reliable.

In the following, we zoom in into the critical region of a block, which encompassed the presentation of Cue2 (between trials 8 and 9), the presentation of the warning signal (between trials 10 and 11), and trials 11 and 12. In Figure 2.3, Mean RT (ms) and Error rate (%) are presented as a function of Cue1 (color or form), Cue2 (color or form), Stimulus congruency on the post-Cue2-trial (incongruent or congruent), and Trial position (8, 9, 10, 11, or 12) [2]. Numerical details about RTs, and performance costs for the critical region of a block are given in Appendix 2A.

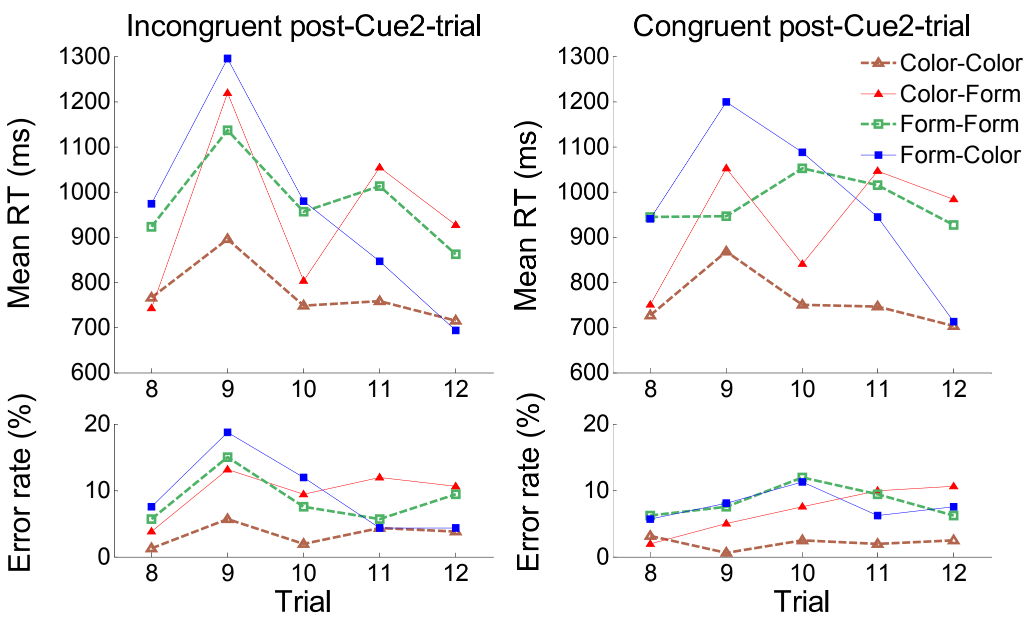

Figure 2.3. Mean RT (ms) and Error rate (%) in Experiment 1 (CPT 200 ms) as a function of Cue1 (color or form), Cue2 (color or form), Stimulus congruency on the post-Cue2-trial (incongruent or congruent), and Trial position (8, 9, 10, 11, or 12).

[2] Trial 8 (i.e. the trial right before Cue2) is included in Figure 2.3, hypothesized to be an imaginary left border of the critical region of a block. Put differently, trial 8 can be seen as the neutral point of departure for the critical region of a block, and trial 12 as the right border at which presumably performance should have stabilized again, i.e. performance should have returned to the baseline level of trial 8.

The first point of interest concerns the post-Cue2-trial (i.e. trial 9). An analysis with factors Block type (Conflict vs. Non-conflict), Actual task performed (Color or Form), and Stimulus congruency on the post-Cue2-trial (Congruent vs. Incongruent) was carried out. The three main effects were significant; Block type, $F(1, 19) = 94.1$, $p < .0001$; Actual task performed, $F(1, 19) = 24.8$, $p < .0001$; and Stimulus congruency, $F(1, 19) = 28.8$, $p < .0001$. There were no reliable two-way interactions (all p's > .1), but the triple interaction between Block type, Actual task performed, and Stimulus congruency was significant, $F(1, 19) = 13$, $p < .01$. When the post-Cue2-trial was incongruent, transition costs were higher on the color match task than on the form match task (325 ms vs. 159 ms), while transition costs were smaller on the color match task than on the form match task (184 ms vs. 254 ms) when the post-Cue2-trial was congruent. Separate analyses for the incongruent and congruent post-Cue2-trial showed that this asymmetry in transition costs with respect to task difficulty was only significant for the incongruent post-Cue2-trial (significant interaction of Block type and Actual task performed, $p < .05$), but not for the congruent post-Cue2-trial (no significant interaction of Block type and Actual task performed, $p > .1$).

For the second trial after Cue2 (i.e. trial 10), we carried out an ANOVA with the same factors as for the post-Cue2-trial. All main effects were significant; Block type, $F(1, 19) = 7$, $p < .05$; Actual task performed, $F(1, 19) = 95.9$, $p < .0001$; and Stimulus congruency, $F(1, 19) = 11.9$, $p < .01$. The two-way interaction Actual task performed by Stimulus congruency was also significant, $F(1, 19) = 5.6$, $p < .05$. This interaction reflects the fact that on the color match task, the status of trial 9 (congruent vs. incongruent) did not modulate RTs, while on the form match task RTs were longer for trial 10 being preceded by a congruent trial 9 than for trial 10 being preceded by an incongruent trial 9.

Next, we will turn to switch costs, i.e. the comparison of the first and the second post-WS-trial (i.e. trials 11 and 12) on conflict blocks. The corresponding analysis had the following factors: Actual task performed (Color or Form), Stimulus congruency (Congruent vs. Incongruent post-Cue2-trial), and Order of execution (First vs. Second post-WS-trial). The three main effects were significant; Actual task performed, $F(1, 19) = 123.6$, $p < .0001$; Stimulus congruency, $F(1, 19) = 4.8$, $p < .05$; and Order of execution, $F(1, 19) = 55.8$, $p < .0001$. The latter effect reflects 143 ms overall switch costs. There was an asymmetry in switch costs due to the task difficulty, resulting in an interaction of Actual task performed and Order of execution, $F(1, 19) = 8.5$, $p < .01$, and a triple interaction of Actual task performed, Stimulus congruency, and Order of execution, $F(1, 19) = 7.2$, $p < .05$. When the post-Cue2-trial was incongruent, the switch costs were approximately equal on the color match task, and on the form match task (151 ms and 127 ms, respectively). When the post-Cue2-trial was congruent, the switch costs were asymmetric, with switch costs of 231 ms on the color match task, and of 62 ms on the form match task.

On non-conflict blocks, we compared performance on the first and on the second post-WS-trial, a difference referred to as restart costs. The ANOVA with factors Actual task performed (Color or Form), Stimulus congruency (Congruent vs. Incongruent post-Cue2-trial), and Order of execution (First vs. Second post-WS-trial) showed main effects of Actual task performed, $F(1, 19) = 167.6$, $p < .0001$; and of Order of execution, $F(1, 19) = 26.8$, $p < .0001$. Performance was faster on the color match task than on the form match task. Participants were slower on the first than on the second post-WS-trial (882 ms vs. 801 ms), resulting in 81 ms restart costs. The restart costs were modulated by task difficulty leading to an interaction of Actual task performed and Order of execution, $F(1, 19) = 8$, $p < .01$. On the color match task, the restart costs were 42 ms, while on the form match task the restart costs were 120 ms.

Errors:

Errors were analyzed in the same way as the reaction time data. Overall, the pattern of errors followed the pattern of reaction times. The descriptive error data and the corresponding statistical analyses are given in Appendix 2B.

Discussion

Cue2 had a clear effect on performance on the two trials following presentation of Cue2 (i.e. trials 9 and 10); performance was slower when Cue2 signaled a task that was different from the one signaled by Cue1 (conflict block) than when Cue2 signaled that participants would have to stay with the original task throughout the remainder of the block (non-conflict block). We will refer to this difference as transition costs.

When the post-Cue2-trial (i.e. trial 9) was incongruent, transition costs were higher on the color match task (i.e. for implementation of the form match task while doing the color match task) than on the form match task. This suggests that the task signaled by Cue2 is implemented during trial 9, and that this implementation requires goal-directed control. This finding also implies that Cue2 is not just picked up as a general indication of the upcoming switch.

It should be noted, however, that the transition costs were not eliminated in case of a congruent post-Cue2-trial. This implies that the slower performance on conflict than on non-conflict blocks on the post-Cue2-trial was not due to an implicit response competition. When, in conflict blocks, participants were implicitly trying out the task indicated by Cue2, this should lead to a response conflict on an incongruent post-Cue2-trial: The response that had actually to be given was different from the response that would have to be given when participants would carry out the task indicated by Cue2. By contrast, on a congruent post-Cue2-trial, the response that had actually to be given and the (implicit) response triggered by a conflicting Cue2 would be identical, and thus no implicit response conflict would be obtained. Thus, it appears that the conflict induced by Cue2 must occur on a higher more abstract level than the implicit execution of the task indicated by Cue2.

On the second trial after Cue2 (i.e. trial 10), performance was better than on the post-Cue2-trial. However, also on trial 10 there were still some (small) transition costs, presumably due to the need to keep the new task in memory while still performing the old task.

On conflict blocks, the difference in performance between the first post-WS-trial and the second post-WS-trial reflects switch costs. These switch costs were asymmetric; there were higher switch costs for switching from the form match task to the color match task than in the opposite direction. In other words, switching from the more difficult (form) task to the less difficult (color) task leads to higher switch costs than switching in the opposite direction. This is in line with Allport's TSI hypothesis, that switching from the more difficult task to the easier task is more time- and effort-consuming than switching in the opposite direction. However, in addition, it turns out that this asymmetry in switch costs is primarily caused by switching in blocks in which the post-Cue2-trial was congruent (as reflected in the significant triple interaction of Actual task performed, Stimulus congruency, and Order of execution).

Finally, on non-conflict blocks, there was evidence for restart costs. These costs appeared irrespective of stimulus congruency on the post-Cue2-trial, but they were modulated by task difficulty. Smaller restart costs on the color match task than on the form match task indicate that a task restart after an interruption could be anticipated more efficiently when the task is the easier one than the more difficult one.

To summarize, implementing a second task while still having to perform the first task incurred transition costs. These costs were not due to an implicit response conflict as they were observed for congruent and incongruent stimuli on the post-Cue2-trial. Thus, the conflict must be located at some higher or more abstract level of task implementation, i.e. goal level. This hypothesis is also supported by the asymmetry in transition costs in case of incongruent post-Cue2-trial, with higher costs for preparing the switch from the easier task to the more difficult task than for the reverse direction. By contrast, switch costs were higher for executing the switch from the more difficult task to the easier task than in the opposite direction in case of congruent post-Cue2-trial. These results lead to the conclusion that for short CPT, the implementation of the task indicated by Cue2 was not completed at Cue2. The implementation of the goal seems to be extended into the post-Cue2-trial.

Experiment 2

The second experiment was a replication of Experiment 1 with only one change. In contrast to Experiment 1, the presentation time for Cue1, Cue2, and the warning signal was not 200 ms, but rather prolonged up to 900 ms. This time interval was chosen because it is in the range of the time interval for which no further reduction of the so-called residual switch costs is obtained (e.g., Allport et al., 1994; De Jong, 2000; Meiran, 1996, 2000a; Meiran et al., 2000; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995).

Method

Participants. Twenty participants, 14 women and 6 men, between the ages of 18 and 35 years took part in Experiment 2. All had normal or corrected-to-normal vision.

Materials, Procedure, and Design were the same as in Experiment 1. There was only one difference: In Experiment 2 the duration of CPT was 900 ms, i.e. Cue1, Cue2, and the warning signal were presented for 900 ms.

Results

Data were analyzed in the same way as in Experiment 1.

The ANOVA for trials 1 to 8 showed a significant main effect of Cue1, $F(1, 19) = 301$, $p < .0001$, reflecting faster performance on the color match task than on the form match task. The significant main effect of Trial position, $F(7, 133) = 39$, $p < .0001$, reflected slower performance on the first trial in a block than on trials 2 to 8. The interaction Cue1 by Trial position was also reliable, $F(7, 133) = 2.6$, $p < .05$. None of the other main effects or interactions were significant.

The ANOVA for trials 13 to 16 revealed a significant effect of Cue2, $F(1, 19) = 215$, $p < .0001$, reflecting faster performance on the color match task than on the form match task. Participants were faster on trials 13 and 14 than on trials 15 and 16, resulting in a reliable main effect of Trial position, $F(3, 57) = 7.4$, $p < .0001$. The two-way interaction Cue1 by Cue2, $F(1, 19) = 17$, $p < .001$, reflected faster performance when Cue1 was the same as Cue2 than when Cue1 and Cue2 were different. The triple interaction Cue1, Cue2, and Trial position was also significant, $F(3, 57) = 3.8$, $p < .05$.

Next, we turn to the critical region of a block, encompassing the presentation of Cue2 (between trials 8 and 9), the presentation of WS (between trials 10 and 11), and trials 11 and 12. Figure 2.4 gives the mean RT (ms) and Error rate (%) as a function of

Cue1 (color or form), Cue2 (color or form), Stimulus congruency on the post-Cue2-trial (incongruent or congruent), and Trial position (8, 9, 10, 11, or 12). Appendix 2C gives the numerical details about RTs and performance costs for the critical region of a block.

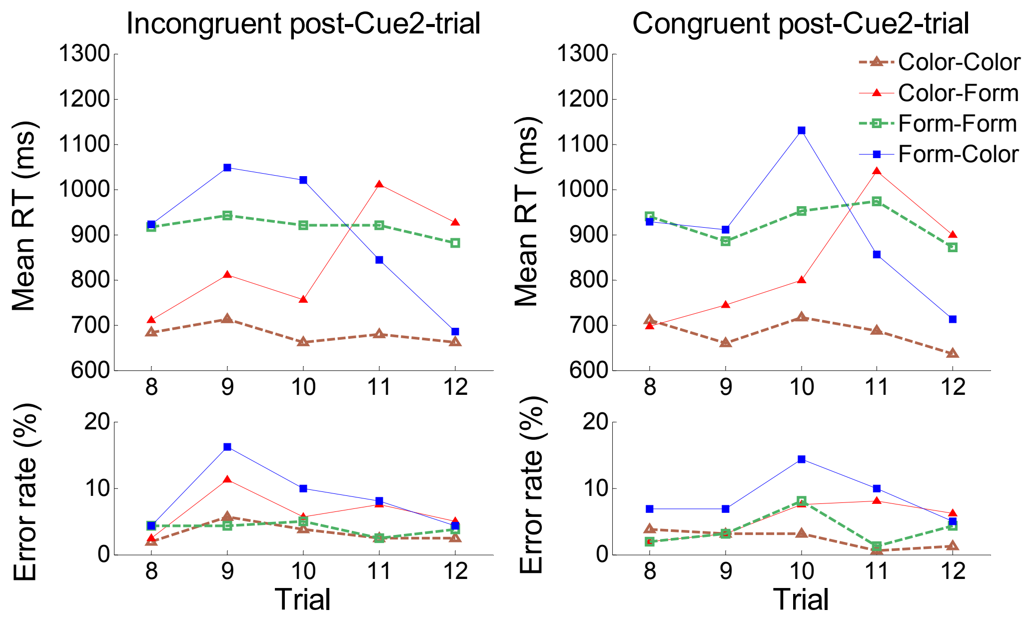

Figure 2.4. Mean RT (ms) in Experiment 2 (CPT 900 ms) as a function of Cue1 (color or form), Cue2 (color or form), Stimulus congruency on the post-Cue2-trial (incongruent or congruent), and Trial position (8, 9, 10, 11, or 12).

For the post-Cue2-trial (i.e. trial 9), an ANOVA with the factors Block type (Conflict vs. Non-conflict), Actual task performed (Color or Form), and Stimulus congruency on the post-Cue2-trial (Congruent vs. Incongruent) was conducted. The main effect of Block type, $F(1, 19) = 12.6$, $p < .01$, indexed better performance on non-conflict than on conflict blocks, and thus, transition costs. The main effect of Actual task performed, $F(1, 19) = 196.8$, $p < .0001$, resulted from faster responding on the color match task than on the form match task. The main effect of Stimulus congruency, $F(1, 19) = 29.8$, $p < .0001$, reflected faster performance on congruent than on incongruent post-Cue2-trial. None of the interactions was reliable, all p's > .1.

For the second trial after Cue2 (i.e. trial 10), the corresponding ANOVA revealed three significant main effects: Block type, Actual task performed, and Stimulus congruency on the post-Cue2-trial. The main effect of Block type, $F(1, 19) = 33.7$, $p < .0001$, reflected faster responding on non-conflict than on conflict blocks. Participants were faster on the color match task than on the form match task, resulting in a main effect of Actual task performed, $F(1, 19) = 152.3$, $p < .0001$. The main effect of Stimulus congruency, $F(1, 19) = 30.2$, $p < .0001$, showed faster performance when trial 10 followed an incongruent trial 9 than a congruent trial 9. None of the interactions was significant, all *p*'s > .05.

The analysis for the first and second post-WS-trial (i.e. trials 11 and 12) on conflict blocks showed significant main effects of Actual task performed, $F(1, 19) = 108.2$, $p < .0001$; and of Order of execution, $F(1, 19) = 35.6$, $p < .0001$. Performance was faster on the color match task than on the form match task. Participants needed more time to perform a task on the first than on the second post-WS-trial, resulting in overall switch costs of 132 ms. None of the interactions was significant, all *p*'s > .2.

On non-conflict blocks, the corresponding ANOVA revealed significant main effects of Actual task performed, $F(1, 19) = 185$, $p < .0001$, and of Order of execution, $F(1, 19) = 31.6$, $p < .0001$. The latter effect reflected slower performance on the first than on the second post-WS-trial, and thus, 53 ms restart costs. These restart costs were modulated by the stimulus congruency on the post-Cue2-trial, resulting in a significant interaction of Order of execution and Stimulus congruency, $F(1, 19) = 4.7$, $p < .05$. The restart costs were 28 ms when the post-Cue2-trial was incongruent, while the restart costs were 77 ms when the post-Cue2-trial was congruent.

Overall, the pattern of errors followed the pattern of reaction times (see Appendix 2D).

Discussion

On the trials intervening between Cue2 and WS (i.e. trials 9 and 10), the difficulty of the task and the status of the post-Cue2-trial (congruent vs. incongruent) affected performance. However, there was no evidence for an asymmetry in transition costs as a function of task difficulty, or as a function of stimulus congruency on the post-Cue2-trial. Thus, the results suggest that for long CPT, the implementation of the task indicated by Cue2 is completed on a goal level at Cue2. This can be seen from the fact that approximately the same size of transition costs as for the post-Cue2-trial (trial 9) is also observed at the next trial, trial 10. This clearly contrasts with Experiment 1 where transition costs on the post-Cue2-trial (trial 9) were much higher than on trial 10. Thus, the transition costs in the present experiment appear to be residual transition costs which are due to the fact that the task implemented at Cue2 has to be kept in memory during the trials intervening between Cue2 and the Warning signal.

The switch costs were not affected by task difficulty. Thus, it appears that providing more time for the processing of Cue2 and WS eliminates the asymmetry in switch costs which was observed in Experiment 1.

In summary, in Experiment 2, prolonged time for processing a task at Cue2 leads to completed goal loading at Cue2. As a consequence, on the post-Cue2-trial, transition costs are neither affected by task difficulty, nor by stimulus congruency. Switch costs were also unaffected by the direction of the task switch and unaffected by stimulus congruency on the post-Cue2-trial.

General Discussion

In the task switching literature, two main views have been proposed concerning the control mechanisms underlying the preparation for and the execution of a task switch.

On the one hand, Monsell (e.g., Monsell, 2003; Monsell et al., 2000; Rogers & Monsell, 1995) has proposed that at the task switch, a consciously initiated task-set reconfiguration (endogenous, goal-directed control) takes place. This task-set reconfiguration is completed by stimulus-driven processing (exogenous control). The task-set reconfiguration is more difficult for a difficult task than for an easy task, leading to an asymmetry in switch costs such that the switch from an easy task to a difficult task incurs higher processing costs than the reverse switch. By contrast, Allport (e.g., Allport et al., 1994; Wylie & Allport, 2000) argues that active disengagement of the previous task takes place at the actual task switch. This process is also referred to as task-set inertia (TSI). This active disengagement is more difficult for a difficult task than for an easy task leading to an asymmetry in switch costs that goes in the opposite direction of the asymmetry observed by Monsell and colleagues.

Thus, we are confronted with two opposing views of task switching, and two corresponding opposite asymmetries in performance costs. In the present study, we do observe both types of asymmetry within one experiment if the cue presentation time is short (CPT 200 ms, Experiment 1). For an incongruent post-Cue2-trial, we observe transition costs that are higher for loading the more difficult form match task while doing the easier color match task than for the reverse situation. Put differently, *preparing* the switch from the easier to the more difficult task is more difficult than *preparing* the switch in the opposite direction.

This result fits well with the assumption of a consciously initiated task-set reconfiguration as proposed by Monsell and colleagues. The assumption of a consciously initiated task-set reconfiguration might also explain why this asymmetry is not present when the post-Cue2-trial is congruent: If the actual task and the task indicated by Cue2 are indistinguishable at a given trial (as is the case for a congruent trial), this might be taken as a signal that a full conscious implementation of the task indicated by Cue2 is not necessary. Put differently, the congruency of the post-Cue2-trial might block in a stimulus-driven manner the conscious, goal-directed control processes for implementing the new task.

This would in turn fit well with the observation that the switch costs (i.e. the costs observed at the actual switch itself, right after the warning signal) are asymmetric after a congruent post-Cue2-trial and symmetric after an incongruent post-Cue2-trial. If the new task has not been fully implemented at the post-Cue2-trial (as we assume for a congruent post-Cue2-trial), the active disengagement from the previous task (in Allport's terms) should be more difficult for the difficult form match task than for the easy color match task leading to an asymmetry in switch costs; the switch from the more difficult to the easier task leads to higher processing costs than the reverse switch. By contrast, if the new task has been fully implemented at the post-Cue2-trial, the actual switch to this new task is unaffected by task difficulty.

The overall pattern of results is clearly different for a long CPT of 900 ms (Experiment 2). First, it appears that loading the new goal is completed at Cue2, and thus does not extend into the post-Cue2-trial. The (symmetric) transition costs for trials 9 and 10 can be seen as reflecting the fact that the new goal has to be kept in memory until the occurrence of the WS (after trial 10). These residual transition costs are therefore unaffected by task difficulty and stimulus congruency, and they extend in approximately constant size throughout the complete interval from Cue2 to WS.

For the long CPT of 900 ms, also switch costs were independent of task difficulty and of stimulus congruency on the post-Cue2-trial. This fits nicely with the assumption that goal loading is completed at Cue2 and thus clearly before the actual task switch.

The difference in performance determined by the factor CPT was confirmed by the outcomes from the additional ANOVAs we carried out; two analyses for the moment of implementation of a new task and two analyses for the moment of the actual task switch. The first two ANOVAs included, respectively, all congruent post-Cue2-trials or all incongruent post-Cue2-trials. These analyses had the factors Block type (Conflict vs. Non-conflict), Actual task performed (Color or Form), and Experiment (1 vs. 2; CPT of 200 ms vs. CPT of 900 ms, respectively). The triple interaction between Block type, Actual task performed, and Experiment reached significance for the incongruent post-Cue2-trial ($F(1, 38) = 7.9$, $p < .01$), but not for the congruent post-Cue2-trial ($p = .080$).

The third ANOVA included the first and the second post-WS-trials when the preceding post-Cue2-trial was congruent. The fourth ANOVA included the first and the second post-WS-trials when the preceding post-Cue2-trial was incongruent. These two analyses had the factors Actual task performed (Color or Form), Order of execution (First vs. Second post-WS-trial), and Experiment (1 vs. 2). The triple interaction between Order of execution, Actual task performed, and Experiment was reliable when the preceding post-Cue2-trial was congruent ($F(1, 38) = 10.6$, $p < .01$), but not when the preceding post-Cue2-trial was incongruent ($p > .4$).

In summary, the present results strongly suggest that both a consciously initiated task-set reconfiguration as proposed by Monsell and colleagues (e.g., Monsell, 2003; Monsell et al., 2000; Rogers & Monsell, 1995) plays a role in task switching as does the active disengagement of the previous task, task-set inertia as proposed by Allport and colleagues (e.g., Allport et al., 1994; Wylie & Allport, 2000). The former process appears to play primarily a role in the *preparation* of a task switch (loading of a new goal on the basis of Cue2) while the latter process appears to play a role primarily for actual *execution* of task switch.

Appendix 2A: Mean RT (ms) for the critical region of a block in Experiment 1 (Cue Presentation Time - 200 ms)

The first table in Appendix 2A shows the mean RT (ms) in Experiment 1 (Cue Presentation Time - 200 ms) on the trials intervening between Cue2 and WS (i.e. trials 9 and 10) as a function of Actual task performed[3] (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial			Congruent post-Cue2-trial		
Task	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Color						
Trial 9	1219	894	325	1051	867	184
Trial 10	803	749	54	839	750	89
Form						
Trial 9	1295	1136	159	1200	946	254
Trial 10	980	956	24	1086	1052	34

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

The second table in Appendix 2A shows the mean RT (ms) in Experiment 1 (Cue Presentation Time - 200 ms) on the first post-WS-trial and on the second post-WS-trial (i.e. trials 11 and 12) as a function of Actual task performed[4] (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial		Congruent post-Cue2-trial	
Task	Conflict	Non-conflict	Conflict	Non-conflict
Color				
1st post-WS-trial	845	757	944	746
2nd post-WS-trial	694	715	713	703
Costs	151	42	231	43
Form				
1st post-WS-trial	1054	1012	1045	1015
2nd post-WS-trial	927	861	983	926
Costs	127	151	62	89

Note. The difference between the first and the second post-WS-trial gives the switch costs (ms) on conflict blocks, and the restart costs (ms) on non-conflict blocks.

[3] On the post-Cue2-trial, when the actual task performed was color, participants prepared the transition from color to form, and when the actual task performed was form, participants prepared the transition from form to color.

[4] On the post-WS-trial, when the actual task performed was color, participants executed the switch from form to color, and when the actual task performed was form, participants executed the switch from color to form.

Appendix 2B: Error rate and statistical analyses of error rate for Experiment 1 (Cue Presentation Time - 200 ms)

For trials 1 to 8, only the two-way interaction Cue1 by Trial position reached significance, $F(7, 133) = 2.5$, $p < .05$. On the color match task, performance was less accurate on trials 1 and 2 than on trials 3 to 8. On the form match task, performance was more accurate on trial 1 than on trials 2 to 8.
For trials 13 to 16, only the main effect of Cue2 was significant, $F(1, 19) = 16.3$, $p < .001$, reflecting more accurate performance on the color match task than on the form match task (3.9 % vs. 6.9 %).
For trial 9 (i.e. the post-Cue2-trial), three main effects were reliable; Block type, $F(1, 19) = 15.2$, $p < .001$, Actual task performed, $F(1, 19) = 13.6$, $p < .01$, and Stimulus congruency, $F(1, 19) = 17$, $p < .001$. The main effect of Block type resulted from less accurate performance on conflict than on non-conflict blocks (11.2 % vs. 7.2 %). The main effect of Actual task performed reflected more accurate performance on the color match task than on the form match task (6.1 % vs. 12.3 %). Performance was less accurate on an incongruent trial 9 than on a congruent trial 9 (13.1 % vs. 5.3 %), resulting in a main effect of Stimulus congruency.
For trial 10, more errors were generated on conflict than on non-conflict blocks (10.0 % vs. 5.9 %), resulting in a main effect of Block type, $F(1, 19) = 8$, $p < .01$. The main effect of Actual task performed, $F(1, 19) = 6.5$, $p < .05$, reflected fewer errors on the color match task than on the form match task (5.3 % vs. 10.6 %).
On conflict blocks, fewer errors were generated on the color match task than on the form match task (5.6 % vs. 10.8 %), resulting in a main effect of Actual task performed, $F(1, 19) = 9.7$, $p < .01$.
On non-conflict blocks, the main effect of Actual task performed was reliable, $F(1, 19) = 11.6$, $p < .01$. Performance was more accurate on the color match task than on the form match task (3.1 % vs. 7.7 %). The triple interaction between Order of execution, Actual task performed, and Stimulus congruency on the post-Cue2-trial was also reliable, $F(1, 19) = 6.1$, $p < .05$.

The first table in Appendix 2B shows the error rate (%) in Experiment 1 (Cue Presentation Time - 200 ms) on the trials intervening between Cue2 and WS (i.e. trials 9 and 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial			Congruent post-Cue2-trial		
Task	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Color						
Trial 9	13.1	5.6	7.5	5.0	0.6	4.4
Trial 10	9.4	1.9	7.5	7.5	2.5	5.0
Form						
Trial 9	18.8	15.0	3.8	8.1	7.5	0.6
Trial 10	11.9	7.5	4.4	11.3	11.9	-0.6

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The second table in Appendix 2B shows the error rate (%) in Experiment 1 (Cue Presentation Time - 200 ms) on the first post-WS-trial and on the second post-WS-trial (i.e. trials 11 and 12) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial		Congruent post-Cue2-trial	
Task	Conflict	Non-conflict	Conflict	Non-conflict
Color				
1st post-WS-trial	4.4	4.4	6.3	1.9
2nd post-WS-trial	4.4	3.8	7.5	2.5
Costs	0.0	0.6	-1.3	-0.6
Form				
1st post-WS-trial	11.9	5.6	10.0	9.4
2nd post-WS-trial	10.6	9.4	10.6	6.3
Costs	1.3	-3.8	-0.6	3.1

Note. The difference between the first and the second post-WS-trial gives the switch costs (%) on conflict blocks, and the restart costs (%) on non-conflict blocks.

Appendix 2C: Mean RT (ms) for the critical region of a block in Experiment 2 (Cue Presentation Time - 900 ms)

The first table in Appendix 2C shows the mean RT (ms) in Experiment 2 (Cue Presentation Time - 900 ms) on the trials intervening between Cue2 and WS (i.e. trials 9 and 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial			Congruent post-Cue2-trial		
Task	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Color						
Trial 9	811	713	98	743	660	83
Trial 10	756	662	94	798	716	82
Form						
Trial 9	1048	943	105	911	886	25
Trial 10	1021	921	100	1131	952	179

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

The second table in Appendix 2C shows the mean RT (ms) in Experiment 2 (Cue Presentation Time - 900 ms) on the first post-WS-trial and on the second post-WS-trial (i.e. trials 11 and 12) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial		Congruent post-Cue2-trial	
Task	Conflict	Non-conflict	Conflict	Non-conflict
Color				
1st post-WS-trial	843	678	855	688
2nd post-WS-trial	686	661	713	636
Costs	157	17	142	52
Form				
1st post-WS-trial	1011	921	1041	974
2nd post-WS-trial	927	882	898	871
Costs	84	39	143	103

Note. The difference between the first and the second post-WS-trial gives the switch costs (ms) on conflict blocks, and the restart costs (ms) on non-conflict blocks.

Appendix 2D: Error rate and statistical analyses of error rate for Experiment 2 (Cue Presentation Time - 900 ms)

For trials 1 to 8, only the main effect of Cue1 was significant, $F(1, 19) = 4.7$, $p < .05$, reflecting more accurate performance on the color match task than on the form match task (2.9 % vs. 4.2 %).
For trials 13 to 16, the two-way interaction Cue1 by Cue2 was reliable, $F(1, 19) = 21.4$, $p < .0001$. This resulted from less accurate performance when Cue2 was different from Cue1 than when Cue2 was the same as Cue1.
For trial 9, two main effects were reliable; Block type, $F(1, 19) = 7.2$, $p < .01$, and Stimulus congruency, $F(1, 19) = 6.5$, $p < .05$. The interaction between Block type and Stimulus congruency was also significant, $F(1, 19) = 4.3$, $p < .05$, and reflected higher transition costs when trial 9 was incongruent than when it was congruent (8.7 % vs. 1.9 %).
For trial 10, performance was less accurate on conflict than on non-conflict blocks (9.4 % vs. 5.0 %), resulting in a main effect of Block type, $F(1, 19) = 7.4$, $p < .01$. The main effect of Actual task performed, $F(1, 19) = 11.5$, $p < .01$, reflected more accurate performance on the color match task than on the form match task (5.0 % vs. 9.4 %).
On conflict blocks, the main effect of Order of execution, $F(1, 19) = 11.3$, $p < .01$, reflected less accurate performance on the first than on the second post-WS-trial (8.4 % vs. 5.2 %, and thus, 3.2 % switch costs).
On non-conflict blocks, none of the main effects or interactions reached significance, all p's > .1.

The first table in Appendix 2D shows the error rate (%) in Experiment 2 (Cue Presentation Time - 900 ms) on the trials intervening between Cue2 and WS (i.e. trials 9 and 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial			Congruent post-Cue2-trial		
Task	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Color						
Trial 9	11.3	5.6	5.6	3.1	3.1	0.0
Trial 10	5.6	3.8	1.9	7.5	3.1	4.4
Form						
Trial 9	16.3	4.4	11.9	6.9	3.1	3.8
Trial 10	10.0	5.0	5.0	14.4	8.1	6.3

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The second table in Appendix 2D shows the error rate (%) in Experiment 2 (Cue Presentation Time - 900 ms) on the first post-WS-trial and on the second post-WS-trial (i.e. trials 11 and 12) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial		Congruent post-Cue2-trial	
Task	Conflict	Non-conflict	Conflict	Non-conflict
Color				
1st post-WS-trial	8.1	2.5	10.0	0.6
2nd post-WS-trial	4.4	2.5	5.0	1.3
Costs	3.8	0.0	5.0	-0.6
Form				
1st post-WS-trial	7.5	2.5	8.1	1.3
2nd post-WS-trial	5.0	3.8	6.3	4.4
Costs	2.5	-1.3	1.9	-3.1

Note. The difference between the first and the second post-WS-trial gives the switch costs (%) on conflict blocks, and the restart costs (%) on non-conflict blocks.

CHAPTER 3

Self-paced preparation of a task switch

Abstract

The present chapter investigates whether participants could perform a task switch without switch costs when they settle the speed for a task switch by their own rhythm. The results of an experiment with the Overlapping Cues Paradigm (OCP) show transition and switch costs despite the fact that participants determined themselves how much time to spend on Cue1, Cue2, and the warning signal, indicating that a self-paced mode in the preparation for and the execution of a task switch is not sufficient to eliminate transition and switch costs.

Introduction

The results from Chapter 2 showed that under time pressure (i.e. the time available for processing a Cue being externally paced) participants could not prepare a task switch in a situation with goals overlapping in time such that switch costs would be eliminated. Therefore, in the current study, we ask whether switch costs can be eliminated when participants settle the performance speed by their own rhythm (i.e. Cue1, Cue2, and the warning signal being self-paced).

Method

Participants. Twenty participants, 13 women and 7 men, between 18 and 30 years old took part in the current experiment. All had normal or corrected-to-normal vision.

Materials, Procedure, and Design were the same as in Experiments 1 and 2 presented in Chapter 2 (for details see Method section of Experiment 1, Chapter 2). There was only one change: In the present experiment, Cue1, Cue2, and the warning signal were self-paced. That is Cue1, Cue2, and warning signal remained on the screen until the participants pushed a response button, indicating that they wanted to proceed with the next trial.

Results

Results were analyzed in the same way as in Experiments 1 and 2 in Chapter 2.

For trials 1 to 8, an ANOVA with the factors Cue1 (Color or Form), Cue2 (Color or Form), Stimulus congruency on the post-Cue2-trial (Congruent or Incongruent), and Trial position (1 to 8) was performed. There was a significant main effect of Cue1, $F(1, 19) = 265$, $p < .0001$, reflecting faster performance on the color match task than on the form match task. The main effect of Trial position was also reliable, $F(7, 133) = 9.3$, p

< .0001, and was due to slower performance on the first trial in a block than on trials 2 to 8. None of the other main effects or interactions approached significance.

In the corresponding ANOVA for trials 13 to 16, there was a significant main effect of Cue2, $F(1, 19) = 246$, $p < .0001$. Participants were again faster in the color match task than in the form match task. A reliable main effect of Trial position, $F(3, 57) = 3.5$, $p < .05$, was due to a slow-down in performance on trial 15. None of the interactions was significant, except the interaction between Cue1, Cue2, Stimulus congruency, and Trial position, $F(3, 57) = 3.4$, $p < .05$.

Figure 3.1 gives the mean RT (ms) and Error rate (%) as a function of Cue1 (color or form), Cue2 (color or form), Stimulus congruency on the post-Cue2-trial (incongruent or congruent), and Trial position (8, 9, 10, 11, or 12). For the critical region of a block, the numerical details for RTs and performance costs are given in Appendix 3A.

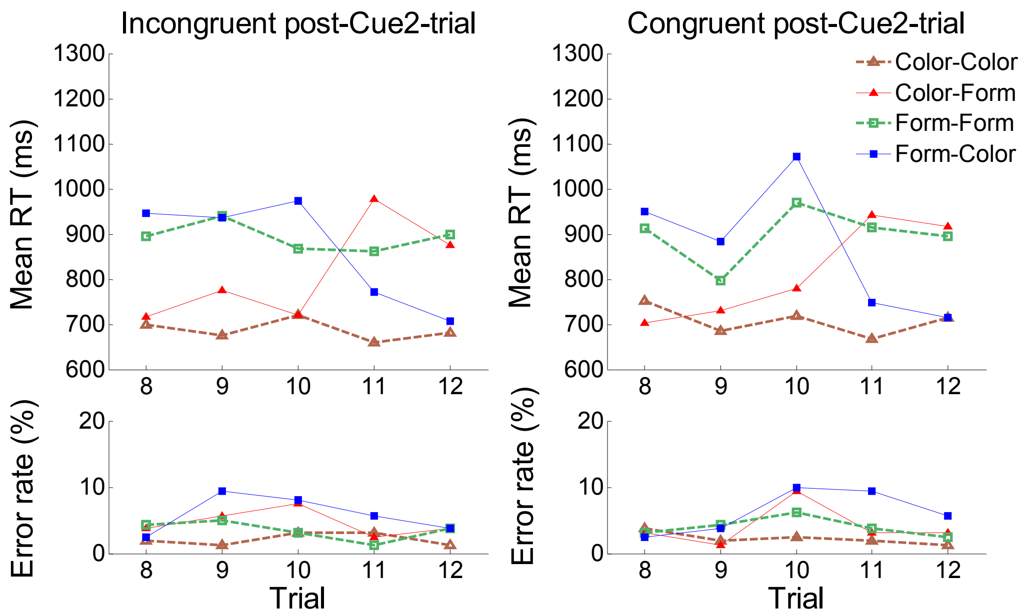

Figure 3.1. Mean RT (ms) and Error rate (%) in Experiment 1 (CPT self-paced) as a function of Cue1 (color or form), Cue2 (color or form), Stimulus congruency on the post-Cue2-trial (incongruent or congruent), and Trial position (8, 9, 10, 11, or 12).

For the post-Cue2-trial (i.e. trial 9), an ANOVA with factors Block type (Conflict vs. Non-conflict), Actual task performed (Color or Form), and Stimulus congruency on the post-Cue2-trial (Congruent vs. Incongruent) was carried out. Participants were slower on conflict than on non-conflict blocks, as revealed by a main effect of Block type, $F(1, 19) = 11.4$, $p < .01$. A main effect of Actual task performed showed better performance on the color match task than on the form match task, $F(1, 19) = 73.3$, $p < .0001$. A significant effect of Stimulus congruency, $F(1, 19) = 15.9$, $p < .001$, reflected faster performance on congruent than on incongruent post-Cue2-trial (774 ms vs. 832 ms). The two-way interaction Stimulus congruency by Actual task performed, $F(1, 19) = 7.4$, $p < .05$, and the three-way interaction between Stimulus congruency, Actual task performed, and Block type, $F(1, 19) = 9.5$, $p < .01$, were significant. The latter three-way interaction reflects the fact that for incongruent trials there were transition costs for color matching (100 ms) but not for form matching (-3 ms), while for congruent trials, the transition costs were smaller for color matching (47 ms) than for form matching (86 ms). A slightly different look at these data shows that on conflict blocks performance was faster on congruent than on incongruent post-Cue2-trial (difference of 45 ms on the color match task and 53 ms on the form match task). In comparison, on non-conflict blocks, the difference between congruent and incongruent trials was eliminated on the color match task (-8 ms) and present on the form match task (142 ms).

For the second trial after Cue2 (i.e. trial 10), an ANOVA with factors Block type (Conflict vs. Non-conflict), Actual task performed (Color or Form), and Stimulus congruency (Congruent vs. Incongruent post-Cue2-trial) was performed. The main effect of Block type, $F(1, 19) = 12.7$, $p < .01$, revealed slower performance on conflict than on non-conflict blocks. The main effect of Actual task performed was also significant, $F(1, 19) = 113.5$, $p < .0001$, reflecting faster performance on the color match task than on the form match task. The main effect of Stimulus congruency, $F(1, 19) = 19$, $p < .0001$, showed slower responding when trial 10 followed a congruent trial 9 than when it followed an incongruent trial 9. The interaction Actual task performed by Block type was significant, $F(1, 19) = 5.2$, $p < .05$. This interaction reflects an asymmetry in transition costs, with higher costs when the actual task performed was form match than when it was color match. The two-way interaction between Actual task performed and Stimulus congruency was also significant, $F(1, 19) = 5.1$, $p < .05$. A closer look at the results shows that for the form match task, performance was around 100 ms slower when trial 10 followed a congruent trial 9 than an incongruent trial 9, on both, conflict and non-conflict blocks. On the color match task, this difference was reduced to 60 ms on conflict blocks, and eliminated on non-conflict blocks. However, the three-way interaction between Actual task performed, Block type, and Stimulus congruency did not reach significance, $p > .1$.

On conflict blocks, the reaction time difference between the first and the second post-WS-trial (i.e. trials 11 and 12) was analyzed in an ANOVA with the factors Actual task performed (Color or Form), Stimulus congruency (Congruent vs. Incongruent post-Cue2-trial), and Order of execution (First vs. Second post-WS-trial). The significant main effect of Order of execution, $F(1, 19) = 8.2$, $p < .01$, showed slower performance on the first than on the second post-WS-trial (860 ms vs. 803 ms), and thus, switch costs. The switch costs were descriptively higher when the post-Cue2-trial was incongruent than when it was congruent (84 ms vs. 30 ms). However, the corresponding interaction Order of execution by Stimulus congruency was not reliable, $F(1, 19) = 3.3$, $p = .084$. The main effect of Actual task performed was significant, $F(1, 19) = 115$, $p < .0001$, reflecting faster performance on the color match task than on the form match task. Neither, the main effect of Stimulus congruency on the post-Cue2-trial, nor any of the interactions reached significance (all p's > .05).

On non-conflict blocks, the corresponding analysis showed only significant main effect of Actual task performed, $F(1, 19) = 135$, $p < .0001$. This resulted from better performance on the color match task than on the form match task. Further, there was no evidence for restart costs, as reflected in the non-significance of the main effect of Order of execution, $p > .1$. None of the interactions approached significance (all p's > .05).

Errors were analyzed in the same way as the reaction time data. Overall, the pattern of errors followed the pattern of reaction times (see Appendix 3B).

Discussion

In the current study we addressed the question whether participants could fully anticipate a task switch when they settle the performance speed by their own rhythm (i.e. Cue1, Cue2, and the warning signal being self-paced) and then completely eliminate transition costs and switch costs. The results showed transition costs despite the fact that participants determined themselves when they wanted to continue after presentation of Cue2 (the average self-paced timing for Cue2 was 1303 ms, with 1101 ms lower bound and 1505 ms upper bound of the 95 % confidence interval). The effect of transition costs was spread out across two trials, i.e. the conflict of holding two tasks active after Cue2 in case of conflict blocks was not restricted to the post-Cue2-trial. More important in the present context, on the post-Cue2-trial, transition costs were independent of task difficulty and stimulus congruency. It should be noted, however, that the performance on trials intervening between Cue2 and WS also showed some differences between blocks with congruent or incongruent stimuli on the post-Cue2-

trial. When the post-Cue2-trial was congruent, the conflict effect was present for both tasks on both trials. This confirms the hypothesis that the conflict induced by Cue2 in a conflict block must occur on an abstract level. When the post-Cue2-trial was incongruent, the conflict effect was located on the post-Cue2-trial for the relatively easier (color) match task, and on the second trial after Cue2 for the relatively more difficult (form) match task.

Although transition costs were not eliminated with self-paced Cue Presentation Time (CPT), there were some differences in performance in comparison to the condition in which participants were under time pressure (Chapter 2). Recall that transition costs were modulated by both task difficulty and stimulus congruency when CPT was 200 ms (Experiment 1 of Chapter 2), while transition costs were unaffected by task difficulty and stimulus congruency when CPT was 900 ms (Experiment 2 of Chapter 2). Furthermore, on Cue2, the self-paced times (i.e. 1303 ms) were longer than 900 ms (i.e. long externally paced CPT). Despite this fact, on the post-Cue2-trial, results for self-paced CPT look more like those for short externally paced CPT (200 ms, Experiment 1 of Chapter 2) than like those for long externally paced CPT (900 ms, Experiment 2 of Chapter 2). Thus, it appears that a long externally paced interval is used more effectively than a completely self-paced interval to prepare a task switch. It is not yet clear what could be the reason for this outcome. However, one could speculate that with a self-paced mode, participants have the illusion of being well prepared for the upcoming task switch. Alternatively, lack of motivation to prepare for the upcoming task switch could be a reason for less efficient preparation with a self-paced interval than with externally paced interval.

Next, we look at the moment of the actual task switch. Switch costs occurred despite the fact that participants determined themselves how much time they spent on the warning signal (the average self-paced timing for WS was 926 ms, with 806 ms lower bound and 1046 ms upper bound of the 95 % confidence interval). It should be noted, however, that these switch costs were reduced in comparison to the switch costs when participants were under time pressure (i.e. Cue1, Cue2, and the warning signal being externally-paced). Thus, at the actual execution of a task switch, a completely self-paced mode is used more effectively than a long externally paced interval.

Furthermore, with a completely self-paced mode, switch costs were symmetrical, i.e. switching to the easier task was as difficult as switching to the more difficult task. Thus, the goal loading of the relevant task seems to be completed at the moment of the actual task switch. Switch costs were descriptively smaller for blocks with a congruent than an incongruent post-Cue2-trial, which could be taken as an indication that the new task has been implemented more firmly when Cue2 is followed by a congruent stimulus. However, this descriptive difference was not statistically significant.

Finally, on non-conflict blocks, there was no evidence for restart costs, presumably due to anticipation of a task restart when CPT is self-paced. This latter result argues against some previous findings (Allport & Wylie, 2000; Gopher, Armony, & Greenshpan, 2000; Monsell, 2003) that restart costs always appear when the instruction specifies continuing with the same task.

To conclude, giving participants opportunity to settle the performance speed by their own rhythm reflects increased ability to prepare for a switch to come. However, the completely self-paced mode is not sufficient to eliminate switch costs. This result supports some previous findings (e.g., Allport, Styles, & Hsieh, 1994; De Jong, 2000; Meiran, 1996, 2000a; 2000b; Meiran, Chorev, & Sapir, 2000; Meiran & Gotler, 2001;

Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995) that so-called residual switch costs could not be eliminated even with prolonged preparation times.

Appendix 3A: Mean RT (ms) for the critical region of a block in Experiment 1 (Cue Presentation Time – Self-paced)

The first table in Appendix 3A shows the mean RT (ms) in Experiment 1 (Cue Presentation Time – Self-paced) on the trials intervening between Cue2 and WS (i.e. trials 9 and 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial			Congruent post-Cue2-trial		
Task	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Color						
Trial 9	776	676	100	731	684	47
Trial 10	720	720	0	779	719	60
Form						
Trial 9	937	940	-3	883	797	86
Trial 10	973	868	105	1072	970	102

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

The second table in Appendix 3A shows the mean RT (ms) in Experiment 1 (Cue Presentation Time – Self-paced) on the first post-WS-trial and on the second post-WS-trial (i.e. trials 11 and 12) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial		Congruent post-Cue2-trial	
Task	Conflict	Non-conflict	Conflict	Non-conflict
Color				
1st post-WS-trial	772	661	749	668
2nd post-WS-trial	706	681	715	714
Costs	66	-20	34	-46
Form				
1st post-WS-trial	977	863	943	915
2nd post-WS-trial	874	898	916	895
Costs	103	-35	27	20

Note. The difference between the first and the second post-WS-trial gives the switch costs (ms) on conflict blocks, and the restart costs (ms) on non-conflict blocks.

Appendix 3B: Error rate and statistical analyses of error rate for Experiment 1 (Cue Presentation Time – Self-paced)

The analyses for trials 1 to 8 and for trials 13 to 16 did not reveal any significant main effects or interactions.
For trial 9 (i.e. the post-Cue2-trial), the main effect of Actual task performed was significant, $F(1, 19) = 7.6$, $p < .01$, reflecting more accurate performance on the color match task than on the form match task (2.5 % vs. 5.6 %). The main effect of Stimulus congruency, $F(1, 19) = 5.9$, $p < .05$, resulted from more accurate performance on a congruent trial 9 than on an incongruent trial 9 (2.8 % vs. 5.3 %). The two-way interaction between Block type and Stimulus congruency, $F(1, 19) = 4.9$, $p < .05$, reflected elimination of transition costs when trial 9 was congruent.
For trial 10, only the main effect of Block type was reliable, $F(1, 19) = 12$, $p < .01$. This resulted from less accurate performance on conflict than on non-conflict blocks (8.7 % vs. 3.7 %).
On conflict blocks, the main effect of Actual task performed, $F(1, 19) = 4.3$, $p < .05$, reflected less accurate performance on the color match task than on the form match task (6.1 % vs. 3.1 %).
On non-conflict blocks, none of the main effects or interactions reached significance all *p*'s > .05.

The first table in Appendix 3B shows the error rate (%) in Experiment 1 (Cue Presentation Time – Self-paced) on the trials intervening between Cue2 and WS (i.e. trials 9 and 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial			Congruent post-Cue2-trial		
Task	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Color						
Trial 9	5.6	1.3	4.4	1.3	1.9	-0.6
Trial 10	7.5	3.1	4.4	9.4	2.5	6.9
Form						
Trial 9	9.4	5.0	4.4	3.8	4.4	-0.6
Trial 10	8.1	3.1	5.0	10.0	6.3	3.8

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The second table in Appendix 3B shows the error rate (%) in Experiment 1 (Cue Presentation Time – Self-paced) on the first post-WS-trial and on the second post-WS-trial (i.e. trials 11 and 12) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Incongruent post-Cue2-trial		Congruent post-Cue2-trial	
Task	Conflict	Non-conflict	Conflict	Non-conflict
Color				
1st post-WS-trial	5.6	3.1	9.4	1.9
2nd post-WS-trial	3.8	1.3	5.6	1.3
Costs	1.9	1.9	3.8	0.6
Form				
1st post-WS-trial	2.5	1.3	3.1	3.8
2nd post-WS-trial	3.8	3.8	3.1	2.5
Costs	-1.3	-2.5	0.0	1.3

Note. The difference between the first and the second post-WS-trial gives the switch costs (%) on conflict blocks, and the restart costs (%) on non-conflict blocks.

CHAPTER 4

The role of the interval between the implementation and the execution of a new task for the actual task switch[1]

Abstract

To investigate the role of the interval between the implementation and the execution of a new task for the actual task switch, we used the Overlapping Cues Paradigm (OCP). Two cues indicated which of two tasks (color match or form match) had to be performed. The cues were presented in a block of 16 trials, Cue1 before trial 1 and Cue2 after trial 8. Several trials after Cue2, a warning signal (WS) appeared. The main manipulation concerned the distance between Cue2 and WS (Cue Warning signal Interval, CWI), with one, two, three, or four trials intervening between Cue2 and WS. Cue Presentation Time (CPT) for Cue1, Cue2, and WS was 200 ms in Experiment 1 and 900 ms in Experiment 2.

The data showed smaller transition costs for preparing a task switch when CPT is long (900 ms) than when CPT is short (200 ms). Switch costs are reduced when the interval between Cue2 and WS is more than one trial. However, there is no further reduction in switch costs with prolonging the interval between Cue2 and WS for more than two trials. Thus, so-called residual switch costs are not due to processing between Cue2 and WS, but rather due to processing at the switch trial itself.

[1] This chapter is almost identical to Bialkova, S. (invited resubmission). The role of the interval between the implementation and the execution of a new task for the actual task switch.

Introduction

Switching from one task to another is usually accompanied with some temporal costs and errors, known as switch costs. Many researchers (Allport, Styles, & Hsieh, 1994; Jersild, 1927; Meiran, 1996; Rogers & Monsell, 1995) interpret switch costs as an index of control processes involved in task switching. However, there is considerable disagreement on what underlies these control processes.

One way to investigate the control processes in task switching is to control the interval for processing a task between the implementation and the actual execution of this task. In this thesis, we introduced the Overlapping Cues Paradigm (OCP) as a way to distinguish two aspects of task switching, the preparation for and the actual execution of a task switch. This contrasts with most of the task switching paradigms (e.g., Allport et al., 1994; Jersild, 1927; Meiran, 1996; Meiran, 2000a, 2000b; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995; Spector & Biederman, 1976; Sudevan & Taylor, 1987), where the preparation for and the execution of a new task take place on the switch trial itself (but see Gopher, Armony, & Greenshpan, 2000; Kleinsorge & Gajewski, 2006; Logan, 2004; Sohn & Anderson, 2001; Sohn & Carlson, 2000 for approaches related to the one used in the present thesis).

Therefore, the main question addressed here is whether and how the interval between the implementation of a new task and the actual execution of this task modulates the actual task switch. To answer this question, two aspects are manipulated, Cue Presentation Time (CPT), and the number of trials intervening between Cue2 and the Warning signal (Cue Warning signal Interval, CWI).

The general principles of the Overlapping Cues Paradigm are explained in the introduction and in Chapter 2. The experiments of the present chapter differ from those in Chapter 2 in the following aspect: While in the experiments of Chapter 2 (see Figure

2.1 in Chapter 2), the WS always appeared two trials after Cue2 (i.e. after trial 10), in the present experiments, the WS appeared either after trial 9, or after trial 10, or after trial 11, or after trial 12. Thus, the distance between Cue2 and WS is one, two, three, or four trials.

As in the experiments of Chapter 2, on the trial right after Cue2 (i.e. trial 9), hereafter referred to as post-Cue2-trial, we manipulate the stimulus congruency (incongruent or congruent, see Figure 2.2 in Chapter 2).

The manipulation of stimulus congruency on the post-Cue2-trial allows to investigate whether and how stimulus-driven control and goal-directed control interact.

In addition to these within-experiment manipulations, we manipulate the Cue Presentation Time (CPT) between experiments. Cue1, Cue2, and WS are presented for 200 ms in Experiment 1 and for 900 ms in Experiment 2.

The first main issue of the present experiments concerns the implementation of a new task while still performing the old one. To address this issue, we will compare performance on the post-Cue2-trial on conflict and non-conflict blocks, hereafter referred to as transition costs. Our design allows us to test whether transition costs depend on task difficulty (color vs. form match task), and on the presentation time for Cue2 (CPT = 200 ms vs. 900 ms). Furthermore, we can test whether transition costs are susceptible to stimulus-driven processes by comparing transition costs for congruent and incongruent post-Cue2-trial.

The second main issue concerns the actual task switch, i.e. performance right after the WS. We will look at the task switch in terms of switch costs, i.e. the difference in performance between the first post-WS-trial and the second post-WS-trial in conflict blocks (Monsell, 2003; Rogers & Monsell, 1995). The central question addressed here is whether and how the Cue Warning signal Interval (CWI) modulates switch costs. For a short CPT, participants do presumably not have enough time at Cue2 to prepare in advance for an upcoming task. Thus, we are interested to know whether the trials intervening between Cue2 and WS (i.e. CWI) can be used for better establishing the new upcoming task while still performing the old task. If this is the case, this should result in better readiness for the upcoming task, and thus, smaller switch costs with longer CWI. Conversely, for a long CPT, participants might have sufficient time at Cue2 to reconfigure and prepare in advance for an upcoming task, and thus the length of CWI should not matter for switch costs. In addition, an asymmetry in switch costs with respect to task difficulty will signal whether the goal loading is completed or not at WS. Finally, we will consider the potential contribution of a stimulus-driven component to switch costs. If the second task is activated in a stimulus-driven manner via a congruent post-Cue2-trial, and if this activation is not suppressed before the WS, switch costs should vary as a function of in-/congruency of the post-Cue2-trial. If there is no stimulus-driven effect, switch costs should appear irrespective of whether the post-Cue2-trial is incongruent or congruent.

In the following we will report two experiments which differ only with respect to Cue Presentation Time; 200 ms in Experiment 1 and 900 ms in Experiment 2. These values were chosen on the basis of the task switching literature which indicates that prolonging preparation time for a task switch up to 600 ms leads to a reduction of switch costs while further prolongation does not lead to a further reduction of the so-called residual switch costs (e.g., Allport et al., 1994; De Jong, 2000; Meiran, 1996, 2000a; Meiran et al., 2000; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995).

Experiment 1

In Experiment 1, the Cue Presentation Time was fixed on 200 ms; Cue1, Cue2, and WS were presented for 200 ms.

Method

Participants

Twenty participants (5 men and 15 women, between the ages of 19 and 29 years) took part in Experiment 1. All had normal or corrected-to-normal vision.

Materials

Stimuli consisted of a reference figure and four match-figures (see Figure 2.2 in Chapter 2). The combinations of form, color, and position of the figures were generated randomly. Each combination appeared only once during the experiment. For half of the stimuli presented on the post-Cue2-trial, the reference figure and the correct match figure had both the same color and the same form, yielding congruent stimuli. The other half of the stimuli presented on the post-Cue2-trial were incongruent (the reference figure and the correct match figure had either the same color or the same form). All other trials were also incongruent.

Design

Cue1 (Color or Form), Cue2 (Color or Form), Stimulus congruency on the post-Cue2-trial (Congruent or Incongruent), and CWI (one, two, three, or four trials intervening between Cue2 and WS) varied within participants.

The experiment consisted of 128 blocks of 16 trials. Presentation order of the blocks was random. Before the experiment there was a short practice session consisting of 6 practice blocks, which were excluded from the data analysis.

Procedure

Each block began with the word “START” (displayed for 1000 ms), followed by Cue1. Cue1 was the Dutch word “VORM” (“FORM”) for matching based on form, or the Dutch word “KLEUR” (“COLOR”) for matching based on color. Cue Presentation Time for Cue1 (as well as for Cue2 and the warning signal) was 200 ms. One hundred milliseconds after Cue1 disappeared, a series of 8 trials appeared on the computer screen for which the participant had to perform the task indicated by Cue1. For each trial, the stimulus remained on the screen until the participant gave a response. The interval from response to trial n to onset of the stimulus for trial n+1 was 100 ms. Two hundred milliseconds after the response on trial 8 a new cue, Cue2 appeared for 200 ms. One, two, three, or four trials after Cue2 (i.e. after trial 9, 10, 11, or 12, respectively), a star was presented as a warning signal (WS). One hundred milliseconds after WS disappeared, the remaining trials of a block were presented. Participants were instructed to keep performing the task indicated by Cue1 for the trials between Cue2 and WS, and to perform the task indicated by Cue2 for the trials after WS. Two hundred milliseconds after the last response of a block (i.e. response to trial 16), a new block started with the word “START” displayed on the screen.

Participants were asked to respond as fast and as accurately as possible with two fingers (index and middle finger) of each hand on a button box with four buttons, which were used to indicate the location of the correct match figure. Feedback asking for faster responding was given if participants did not respond within 2000 ms.

Results

Reaction times (RTs) were recorded for all 16 trials of each block. Incorrect responses and out- of- time- responses (trials with RT longer than 2000 ms) were also registered.

Reaction times:

RTs for trials 1 to 8 (i.e. trials intervening between Cue1 and Cue2) were examined with a repeated measures analysis of variance (ANOVA) with the factors Cue1 (Color or Form), Cue2 (Color or Form), Stimulus congruency on the post-Cue2-trial (Congruent or Incongruent), CWI (one, two, three, or four trials), and Trial position (1 to 8). The analysis showed a significant main effect of Cue1, $F(1, 19) = 251$, $p < .0001$. Participants were faster on the color match task than on the form match task. The main effect of Trial position was also reliable, $F(7, 133) = 22.7$, $p < .0001$, reflecting slower performance on the first trial of a block than on trials 2 to 8. None of the other main effects or interactions approached significance. This is consistent with what one should expect, because only Cue1 and Trial position are real experimental factors for trials 1 to 8 while all other factors are in fact dummy factors; they only can play a role in the critical region of a block where Cue2 and WS are presented.

This critical region starts at the post-Cue2-trial (i.e. trial 9). Note that on the post-Cue2-trial, participants continued with the task indicated by Cue1. Reaction times on the post-Cue2-trial were analyzed with an ANOVA with the factors Block type (Conflict vs. Non-conflict), Actual task performed (Color or Form), Stimulus congruency on the post-Cue2-trial (Congruent vs. Incongruent), and CWI (one, two, three, or four trials). Table 4.1 shows RTs and transition costs (difference between conflict and non-conflict blocks) on the post-Cue2-trial. Note that on the post-Cue2-trial, when the actual task performed was color, participants prepared the transition from color to form, and when the actual task performed was form, participants prepared the transition from form to color.

Table 4.1

Mean RT (ms) in Experiment 1 (Cue Presentation Time - 200 ms) on the post-Cue2-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent). Standard errors of the mean in parentheses

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent	999 (31)	769 (32)	230	1185 (39)	1035 (32)	150
Congruent	937 (28)	720 (20)	217	1017 (41)	859 (27)	158

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

Performance was faster on the color match task than on the form match task, resulting in a significant main effect of Actual task performed, $F(1, 19) = 59.6$, $p < .0001$. The significant main effect of Block type, $F(1, 19) = 95.8$, $p < .0001$, reflected slower performance on conflict than on non-conflict blocks, i.e. average transition costs of 189 ms. These transition costs were higher when the actual task performed was the color match task (224 ms) than when it was the form match task (154 ms), as reflected in a significant two-way interaction of Actual task performed and Block type, $F(1, 19) = 6.7$, $p < .05$. The main effect of Stimulus congruency was significant, $F(1, 19) = 47.4$, $p < .0001$, and resulted from faster responding on a congruent than on an incongruent post-Cue2-trial. However, Stimulus congruency did not modulate transition costs, as reflected in a non-significant interaction between Block type and Stimulus congruency, $p > .9$. The two-way interaction between Actual task performed and Stimulus congruency was reliable, $F(1, 19) = 16.7$, $p < .001$. On the form match task, participants were 173 ms faster when the post-Cue2-trial was congruent than when it was incongruent. By contrast, on the color match task, the difference between congruent and incongruent post-Cue2-trial was reduced to 56 ms. The main effect of CWI and any interactions of the other factors with CWI were not significant, all p's >. 2. This is in accordance with what one could expect because an effect of CWI can only emerge after the post-Cue2-trial.

Mean RTs and the performance costs for the first trial and for the second trial after WS (hereafter referred to as first post-WS-trial and second post-WS-trial, respectively) are given in Table 4.2.

Table 4.2

Mean RT (ms) in Experiment 1 (Cue Presentation Time - 200 ms), on the first post-WS-trial and on the second post-WS-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Cue Warning signal Interval (one, two, three, or four trials), respectively, top panel - when the post-Cue2-trial was incongruent, down panel - when the post-Cue2-trial was congruent. Standard errors of the mean in parentheses

	Color match task		Form match task	
CWI	Conflict	Non-conflict	Conflict	Non-conflict
One trial				
1st post-WS-trial	830 (47)	730 (37)	1013 (35)	964 (41)
2nd post-WS-trial	663 (30)	639 (23)	908 (38)	840 (29)
Costs	167	91	105	124
Two trials				
1st post-WS-trial	742 (28)	655 (28)	938 (31)	903 (32)
2nd post-WS-trial	634 (26)	643 (29)	853 (34)	873 (31)
Costs	108	12	85	30
Three trials				
1st post-WS-trial	730 (30)	693 (33)	932 (36)	897 (27)
2nd post-WS-trial	620 (21)	636 (28)	862 (30)	837 (28)
Costs	110	57	70	60
Four trials				
1st post-WS-trial	755 (35)	686 (36)	974 (33)	952 (43)
2nd post-WS-trial	614 (30)	638 (28)	841 (35)	847 (31)
Costs	141	48	133	105

	Color match task		Form match task	
CWI	Conflict	Non-conflict	Conflict	Non-conflict
One trial				
1st post-WS-trial	853 (41)	694 (26)	986 (37)	933 (35)
2nd post-WS-trial	683 (35)	655 (31)	882 (35)	845 (33)
Costs	170	39	104	88
Two trials				
1st post-WS-trial	805 (42)	671 (29)	1012 (41)	916 (37)
2nd post-WS-trial	633 (30)	626 (20)	884 (37)	875 (47)
Costs	172	45	128	41
Three trials				
1st post-WS-trial	763 (39)	690 (24)	969 (41)	900 (38)
2nd post-WS-trial	631 (29)	626 (27)	890 (42)	834 (30)
Costs	132	64	79	66
Four trials				
1st post-WS-trial	721 (20)	667 (26)	911 (36)	914 (27)
2nd post-WS-trial	621 (27)	635 (21)	837 (26)	863 (34)
Costs	100	32	74	51

Note. The difference between the first and the second post-WS-trial gives the switch costs (ms) on conflict blocks, and the restart costs (ms) on non-conflict blocks.

Note that on the post-WS-trial, when the actual task performed was color, participants executed the switch from form to color, and when the actual task performed was form, participants executed the switch from color to form.

The corresponding analysis for comparing the performance on the first and the second post-WS-trial on conflict blocks (i.e. switch costs) had the factors Order of execution (First vs. Second post-WS-trial), Actual task performed (Color or Form), CWI (one, two, three, or four trials), and Stimulus congruency (Congruent vs. Incongruent post-Cue2-trial).

The main effects of Order of execution, of Actual task performed, and of CWI were reliable. The main effect of Order of execution, $F(1, 19) = 85$, $p < .0001$, reflected slower performance on the first post-WS-trial than on the second post-WS-trial (871 ms vs. 754 ms), and thus, 117 ms switch costs. The effect of Actual task performed, $F(1, 19) = 286$, $p < .0001$, resulted from faster performance on the color match task than on the form match task. The effect of CWI, $F(3, 57) = 9.7$, $p < .0001$, resulted from faster performance with longer CWI. The two-way interaction between Order of execution and Actual task performed, $F(1, 19) = 4.7$, $p < .05$, reflected an asymmetry in switch costs, with higher costs for the switch from form to color (137 ms) than in the opposite direction (97 ms). None of the other interactions was reliable, all p's > .05.

In addition, we compared the performance on the first and on the second post-WS-trial on non-conflict blocks, and thus in terms of restart costs (Allport & Wylie, 2000; Gopher et al., 2000; Monsell, 2003). The corresponding ANOVA had the factors Order of execution (First vs. Second post-WS-trial), Actual task performed (Color or Form), CWI (one, two, three, or four trials), and Stimulus congruency (Congruent vs. Incongruent post-Cue2-trial). The main effects of Order of execution, $F(1, 19) = 22.7$, $p < .0001$, and of Actual task performed, $F(1, 19) = 188$, $p < .0001$, were significant.

Participants were slower on the first post-WS-trial than on the second post-WS-trial, reflecting 60 ms restart costs. Performance was faster on the color match task than on the form match task. None of the other main effects or interactions reached significance, all p's > .1.

Errors:

Errors were analyzed in the same way as the RTs. Overall, the pattern of errors followed the pattern of RTs. Appendix 4A gives the descriptive error data and the statistically significant main effects and interactions.

Discussion

With respect to the first main issue, the implementation of a new task while still performing the old one, the following picture emerges: On the post-Cue2-trial, the slower performance on conflict than on non-conflict blocks reflected transition costs. These transition costs were asymmetric, with higher costs when Cue2 required the loading of the more difficult (form match) task while still performing the easier (color match) task than when Cue2 required the loading of the easier task while still performing the more difficult task. Thus, the preparation for the (upcoming) switch from the easier task to the more difficult task was harder than in the opposite direction. This asymmetry in transition costs indicates that the implementation of the new task initiated by Cue2 is not completed before the post-Cue2-trial. It appears that the loading of the new goal is partly carried out in parallel with the post-Cue2-trial, and therefore affects performance on this trial. Transition costs appeared irrespective of stimulus congruency on the post-Cue2-trial, despite the fact that performance was overall faster on congruent than on incongruent trials. Thus, the implementation of the new goal indicated by Cue2 seems to be unaffected by stimulus-driven processes. However, stimulus congruency interacted with type of the actual task performed. The relatively difficult (form match) task was affected more by stimulus congruency than the relatively easy (color match) task. In other words, the activation of the irrelevant task in a stimulus-driven manner seems to be more pronounced when the actual task performed was the relatively difficult task than when it was the relatively easy one.

Concerning the second main issue, the actual task switch right after WS, switch costs appeared irrespective of CWI, and irrespective of stimulus congruency of the post-Cue2-trial. Furthermore, switch costs were asymmetric, with higher costs for switching from the form match task to the color match task than in the opposite direction, presumably due to not completed goal loading at the actual task switch. Note that the asymmetry in switch costs is in the opposite direction of the asymmetry in transition costs. That is, while the *preparation* for a switch from the easier task to the more difficult task appears to be harder than the preparation for the reverse switch, the *actual switch* is harder for going from the more difficult to the easier task than the actual switch in the other direction.

Finally, on non-conflict blocks, there were restart costs. Restart costs occurred irrespective of task difficulty and irrespective of stimulus congruency on the post-Cue2-trial. Although statistically restart costs did not differ with respect to CWI, descriptively, restart costs showed some differences with respect to CWI.

In summary, for short externally paced CPT (200 ms), switch costs did not differ with respect to CWI. Transition costs were higher for the transition from the easier task to the more difficult task than in the opposite direction, while switch costs were higher for the switch from the more difficult task to the easier task than in the opposite direction. Thus, the time lost at the moment of the implementation of a new task turns into a time gain at the moment of the actual execution of this task. These findings support the outcomes from Experiment 1 of Chapter 2. We will discuss this issue in more detail in Chapter 6.

Experiment 2

Experiment 2 replicated Experiment 1 with only one change. In Experiment 2, the Cue Presentation Time (CPT) was prolonged to 900 ms (i.e. Cue1, Cue2, and WS were presented for 900 ms), that is, to a time for which it is known that so-called residual switch costs are not further reduced by providing more time (e.g., Allport et al., 1994; De Jong, 2000; Meiran, 1996, 2000a; Meiran et al., 2000; Monsell et al., 2000; Rogers & Monsell, 1995).

Method

Participants

Twenty participants (6 men and 14 women, between the ages of 19 and 26 years) took part in this experiment. All had normal or corrected-to-normal vision.

Materials, Design, and Procedure were the same as in Experiment 1, with only one difference: in Experiment 2, CPT was fixed on 900 ms, that is, Cue1, Cue2, and WS appeared for 900 ms.

Results

Results were analyzed in the same way as in Experiment 1.

The ANOAVA for trials 1 to 8 (i.e. trials intervening between Cue1 and Cue2) showed faster responding on the color match task than on the form match task, resulting in a significant main effect of Cue1, $F(1, 19) = 250$, $p < .0001$. The reliable main effect of Trial position, $F(7, 133) = 21.3$, $p < .0001$, reflected slower performance on the first trial of a block than on trials 2 to 8. None of the other main effects or interactions were significant.

RTs and transition costs on the post-Cue2-trial are presented in Table 4.3.

Table 4.3

Mean RT (ms) in Experiment 2 (Cue Presentation Time - 900 ms) on the post-Cue2-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent). Standard errors of the mean in parentheses

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent	736 (30)	673 (19)	63	921 (31)	883 (30)	38
Congruent	715 (21)	629 (23)	86	846 (25)	799 (31)	47

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

For the post-Cue2-trial, the analysis revealed significant main effects of Block type, of Actual task performed, and of Stimulus congruency on the post-Cue2-trial. The main effect of Block type, $F(1, 19) = 25.4$, $p < .0001$, reflected faster responding on non-conflict than on conflict blocks, and thus, 58 ms transition costs. The main effect of Actual task performed, $F(1, 19) = 256$, $p < .0001$, resulted from faster responding on the color match task than on the form match task. Participants were faster on congruent than on incongruent post-Cue2-trial, resulting in a main effect of Stimulus congruency on the post-Cue2-trial, $F(1, 19) = 29.9$, $p < .0001$. Stimulus congruency interacted with Actual task performed, $F(1, 19) = 12.4$, $p < .01$. On the form match task, performance was about 80 ms faster when the post-Cue2-trial was congruent than when it was incongruent. On the color match task, this difference between congruent and incongruent post-Cue2-trial was reduced to 33 ms. The main effect of CWI was not reliable, $p > .3$. None of the other interactions reached significance, all p's $> .1$.

RTs on the first and on the second post-WS-trial and performance costs (switch and restart costs) are shown in Table 4.4.

Table 4.4

Mean RT (ms) in Experiment 2 (Cue Presentation Time - 900 ms), on the first post-WS-trial and on the second post-WS-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Cue Warning signal Interval (one, two, three, or four trials), respectively, top panel - when the post-Cue2-trial was incongruent, down panel - when the post-Cue2-trial was congruent. Standard errors of the mean in parentheses

	Color match task		Form match task	
CWI	Conflict	Non-conflict	Conflict	Non-conflict
One trial				
1st post-WS-trial	759 (44)	675 (42)	980 (40)	898 (38)
2nd post-WS-trial	618 (31)	634 (31)	852 (34)	829 (32)
Costs	141	41	128	69
Two trials				
1st post-WS-trial	697 (37)	632 (20)	913 (49)	841 (41)
2nd post-WS-trial	651 (31)	610 (21)	875 (44)	842 (32)
Costs	46	22	38	-1
Three trials				
1st post-WS-trial	707 (43)	655 (36)	937 (35)	851 (30)
2nd post-WS-trial	618 (21)	623 (31)	842 (35)	761 (21)
Costs	89	32	95	90
Four trials				
1st post-WS-trial	703 (36)	595 (24)	974 (31)	886 (42)
2nd post-WS-trial	641 (37)	619 (22)	804 (34)	864 (41)
Costs	62	-24	170	22

	Color match task		Form match task	
CWI	Conflict	Non-conflict	Conflict	Non-conflict
One trial				
1st post-WS-trial	850 (52)	642 (34)	951 (57)	906 (36)
2nd post-WS-trial	701 (33)	625 (23)	849 (37)	826 (34)
Costs	149	17	102	80
Two trials				
1st post-WS-trial	716 (41)	626 (24)	980 (46)	839 (29)
2nd post-WS-trial	666 (48)	617 (17)	838 (31)	855 (36)
Costs	50	9	142	-16
Three trials				
1st post-WS-trial	717 (51)	611 (26)	939 (38)	878 (41)
2nd post-WS-trial	681 (36)	620 (30)	861 (37)	829 (34)
Costs	36	-9	78	49
Four trials				
1st post-WS-trial	749 (50)	654 (28)	945 (32)	893 (37)
2nd post-WS-trial	641 (32)	621 (22)	848 (40)	829 (33)
Costs	108	33	97	64

Note. The difference between the first and the second post-WS-trial gives the switch costs (ms) on conflict blocks, and the restart costs (ms) on non-conflict blocks.

For the first and the second post-WS-trial on conflict blocks, an ANOVA was conducted with the factors Order of execution (First vs. Second post-WS-trial), Actual task performed (Color or Form), CWI (one, two, three, or four trials), and Stimulus congruency (Congruent vs. Incongruent post-Cue2-trial). Performance was faster on the color match task than on the form match task, resulting in a main effect of Actual task performed, $F(1, 19) = 171$, $p < .0001$. The main effect of Stimulus congruency, $F(1, 19) = 5$, $p < .05$, reflected faster performance when the post-Cue2-trial was incongruent than when it was congruent (786 ms vs. 808 ms). The significant main effect of Order of execution, $F(1, 19) = 28.3$, $p < .0001$, reflected slower performance on the first post-WS-trial than on the second post-WS-trial, and thus, 96 ms switch costs. Descriptively, there was a large variability in switch costs over CWI. However, the two-way interaction between Order of execution and CWI was not reliable, $F(3, 57) = 2.4$, $p = .076$. None of the other interactions reached significance, all p’s > .1.

On non-conflict blocks, two main effects were significant; Order of execution, $F(1, 19) = 7$, $p < .05$, and Actual task performed, $F(1, 19) = 353$, $p < .0001$. The main effect of Order of execution reflected slower responding on the first post-WS-trial than on the second post-WS-trial, and thus, around 30 ms restart costs. Performance was faster on the color match task than on the form match task, resulting in the main effect of Actual task performed. There was an asymmetry in restart costs determined by task difficulty, leading to a significant two-way interaction between Actual task performed and Order of execution, $F(1, 19) = 5.9$, $p < .05$. On the form match task, restart costs were 45 ms, while on the color match task, restart costs were reduced to 15 ms. There were no other reliable main effects or interactions, all p’s > .1.

Overall, the results on errors followed those for reaction times (see Appendix 4B).

Discussion

In Experiment 2, the long CPT of 900 ms led to a reduction of transition costs on the post-Cue2-trial. The asymmetry in transition costs with respect to task difficulty, that was observed in Experiment 1, disappeared with the long CPT in the present Experiment. Thus it appears that the long CPT of 900 ms allows participants to complete the implementation of the new task at goal level during the presentation of Cue2. Transition costs did not differ with respect to stimulus congruency. However, performance was faster when the post-Cue2-trial was congruent than when it was incongruent. The difference in performance between congruent and incongruent post-Cue2-trial was more pronounced on the relatively difficult (form match) task. In other words, when the relevant task is not well established, the irrelevant task receives additional activation in a stimulus-driven manner via a congruent post-Cue2-trial.

On conflict blocks, descriptively, switch costs were higher when CWI was one trial than when it was more trials. A closer look at the results showed that on the first post-WS-trial, performance was slower when CWI was one trial than when it was more trials, while on the second post-WS-trial, there was no difference in performance with respect to CWI. However, the interaction between Order of execution and CWI did not reach significance. Neither the type of the actual task performed, nor stimulus congruency on the post-Cue2-trial affected switch costs.

And finally, on non-conflict blocks, elimination of restart costs on the color match task evidenced that continuing with the same task after an interruption could be anticipated in the case of the relatively easy task. This finding argues against some previous findings (Allport & Wylie, 2000; Gopher et al., 2000; Monsell, 2003) that restart costs could not be eliminated even when the instruction requires continuing with the same task after an interruption. Although the interaction between Order of execution and CWI did not reach significance, descriptively, there was an elimination of restart costs when CWI was two trials intervening between Cue2 and WS. Thus, it appears that two trials is the optimum distance between Cue2 and WS for a task restart.

In sum, in Experiment 2, prolonged CPT to 900 ms leads to completed goal loading at Cue2. This is reflected in symmetric transition costs with respect to task difficulty (as opposed to the asymmetry observed in Experiment 1). These results are consistent with the results from Experiment 2 of Chapter 2. We will come back to this issue in Chapter 6. Furthermore, switch costs were not modulated by task difficulty. This is presumably due to completed goal loading at the actual task switch. Although, descriptively, switch costs showed some variation as a function of CWI this result was not substantiated statistically.

General discussion

In the present experiments, we investigated whether and how the interval between Cue2 and WS (i.e. the number of trials intervening between Cue2 and WS) modulates the preparation for and the execution of a task switch. To address this question, we separated the preparation for a new task while still doing an old task from the actual switch to this new task. The preparation could take place at Cue2 (which was presented for 200 ms or 900 ms in Experiments 1 and 2, respectively) and/or at the trials intervening between Cue2 and the warning signal. The eventual effectiveness of this preparation for the actual task switch, on the other hand, should be reflected at the actual switch (i.e. right after the warning signal), and can be looked at in terms of switch costs (i.e. difference in performance between the first and the second post-WS-trial).

Let us first have a look at the preparation for a new task. For a short CPT of 200 ms (Experiment 1), the transition costs (i.e. the RT-difference between conflict and non-conflict blocks on the post-Cue2-trial) vary as a function of the combination of the actual task performed and the new task to be implemented. The transition costs are higher for implementing the (difficult) form match task while doing the (easy) color match task than for the reverse task constellation. This asymmetry allows for a couple of conclusions concerning the nature of the preparation for the new task. First, if the preparation at Cue2 would be task-unspecific, i.e. if Cue2 would only be picked up as an indicator that one has to implement a new task at the warning signal, we would not expect the observed asymmetry in transition costs. Second, it appears that a CPT of 200 ms is not long enough for completion of the goal loading at Cue2. Rather, the goal loading appears to extend into the post-Cue2-trial. Third, it appears that the difference in the amount of resources that are required to actually perform the color match task or the form match task is smaller than the difference in the amount of resources that are required for implementing the color task or the form task. If the difference between actually executing the one or the other task would be as large as the difference between implementing the one or the other task, the net resources that are required for implementing the easy task while doing the difficult one should be the same as those required for implementing the difficult task while doing the easy task. This conclusion also makes sense because the actual task has already been performed on 8 trials preceding Cue2, and thus should be established very firmly such that resource requirements will be rather low.

For a CPT of 900 ms (Experiment 2), we get a clearly different picture. Now, transition costs are much smaller than for the short CPT, and they are not asymmetric anymore. Thus, transition costs for CPT 900 ms can be seen as “residual transition costs" (in analogy to residual switch costs, e.g., Allport et al., 1994; De Jong, 2000; Meiran et al., 2000; Monsell et al., 2000; Rogers & Monsell, 1995). A plausible interpretation of these residual transition costs would be that (most of) the task specific preparation for the new task has been done during the presentation of Cue2, and that the remaining costs reflect the process of keeping the new task in memory while still performing the old task.

Finally, in-/congruency of the post-Cue2-trial did not matter for the pattern of transition costs in neither experiment. This suggests that the implementation of the new task was not affected by stimulus-driven processes. This does, however, not preclude the possibility that stimulus in-/congruency of the post-Cue2-trial might have an impact for the actual switch itself.

Let us next turn to the actual switch (i.e. right after a warning signal). We will look at the switch costs (i.e. the difference between the first and the second post-WS-trial on conflict blocks) by aggregating the data across the factor Stimulus congruency (congruent vs. incongruent post-Cue2-trial), because none of the interactions of Stimulus congruency with other factors reached significance. This way of looking at the data provides the opportunity to have more observations per condition.

For switch costs, two scenarios can be considered. First, if the trials intervening between Cue2 and WS are used for parallel establishment of the second task while still running the first task, one would expect a monotonic decrease of switch costs with longer CWI. Second, if the trials between Cue2 and WS lead to a suppression of the second task while still running the first task, one could expect a monotonic increase of switch costs with longer CWI. Actually, neither scenario is supported by our data (see Figure 4.1).

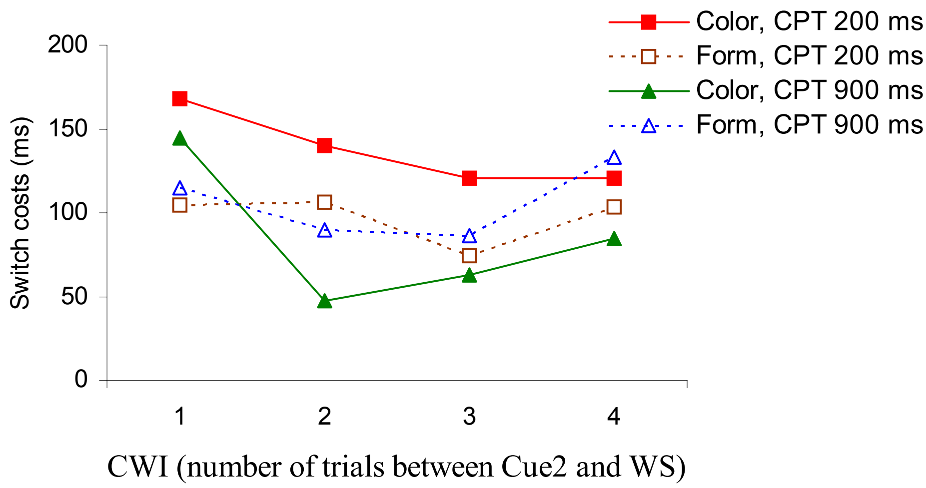

Figure 4.1. Switch costs (ms) in Experiment 1 (Cue Presentation Time - 200 ms) and in Experiment 2 (Cue Presentation Time - 900 ms) as a function of Cue Warning signal Interval (one, two, three, or four trials intervening between Cue2 and Warning signal), and Actual task performed (color or form).

When the actual task performed was the form match task (dashed lines in Figure 4.1), switch costs appeared irrespective of CWI (non-significant interaction between Order of execution and CWI; $p > .8$ for CPT 200 ms, and $p > .5$ for CPT 900 ms). When the actual task performed was the color match task (solid lines in Figure 4.1), switch costs were highest when CWI was one trial. This result was substantiated statistically for CPT 900 ms (Order of execution by CWI; $p < .05$), but not for CPT 200 ms (Order of execution by CWI; $p > .3$). A closer look at the results for CPT 900 ms shows that when CWI was more than one trial, switch costs did not differ with respect to CWI. Put differently, prolongation of CWI to more than two trials does not lead to a further reduction of the switch costs.

To summarize, the interval between Cue2 and WS modulates the preparation for a task switch. When the time available for processing a task at the moment of implementation (i.e. at Cue2) is long (e.g., CPT 900 ms), the goal loading seems to be completed at Cue2. By contrast, when the time available for processing a task at the moment of implementation is short (e.g., CPT 200 ms), the goal loading is not completed at Cue2. This is reflected in an asymmetry in transition costs with higher costs for preparing the switch from the easier task to the more difficult task than in the opposite direction. As a consequence, at the actual execution of a task switch, switch costs are smaller for executing the switch from the easier task to the more difficult task than in the opposite direction. Thus, the time lost at the preparation for a task switch turns into a gain at the actual execution of a task switch. Finally, switch costs can not be eliminated completely even when providing participants with more trials between Cue2 and WS (i.e. longer CWIs).

In sum, the results from the present study suggest that prolonged interval for processing a task (between the implementation and the execution of this task) facilitates the preparation for a task switch. However, there were some residual switch costs. Thus, it seems that the residual switch costs are not due to processing between Cue2 and WS, but rather due to processing at the switch trial itself. These results support some previous findings (e.g., Chapter 3, but see also Allport et al., 1994; De Jong, 2000; Meiran, 1996, 2000a; 2000b; Meiran et al., 2000; Meiran & Gotler, 2001; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995) that residual switch costs could not be eliminated even with prolonged preparation times.

Appendix 4A: Accuracy data for Experiment 1 (Cue Presentation Time - 200 ms)

For trials 1 to 8, only the main effect of Cue1 reached significance, $F(1, 19) = 10.8$, $p < .01$, reflecting more accurate performance on the color match task than on the form match task (2.7 % vs. 4.3 %).
For the post-Cue2-trial (i.e. trial 9), three main effects were significant; Block type, Actual task performed, and Stimulus congruency. The main effect of Block type, $F(1, 19) = 7.2$, $p < .01$, resulted from more accurate performance on non-conflict than on conflict blocks (6.2 % vs. 9.1 %). The main effect of Actual task performed, $F(1, 19) = 7.9$, $p < .01$, reflected better performance on the color match task than on the form match task (6.3 % vs. 8.9 %). The main effect of Stimulus congruency, $F(1, 19) = 45.5$, $p < .0001$, resulted from less accurate performance on incongruent than on congruent trials 9 (12.0 % vs. 3.2 %).
On conflict blocks, only the main effect of CWI was significant, $F(3, 57) = 4.9$, $p < .005$. Participants generated more errors when CWI was one trial than when it was more trials.
On non-conflict blocks, the main effect of Actual task performed, $F(1, 19) = 15.8$, $p < .001$, resulted from more accurate performance on the color match task than on the form match task (2.0 % vs. 4.9 %).

The first table in Appendix 4A shows the error rate (%) in Experiment 1 (Cue Presentation Time - 200 ms) on the post-Cue2-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent	13.1	8.1	5.0	15.0	11.9	3.1
Congruent	2.2	1.9	0.3	5.9	2.8	3.1

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The second table in Appendix 4A shows the error rate (%) in Experiment 1 (Cue Presentation Time - 200 ms), on the first post-WS trial and on the second post-WS-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Cue Warning signal Interval (one, two, three, or four trials), respectively, top panel - when the post-Cue2-trial was incongruent, down panel - when the post-Cue2-trial was congruent

	Color match task		Form match task	
CWI	Conflict	Non-conflict	Conflict	Non-conflict
One trial				
1st post-WS-trial	8.8	1.3	6.3	3.8
2nd post-WS-trial	6.3	3.8	6.3	2.5
Costs	2.5	-2.5	0.0	1.3
Two trials				
1st post-WS-trial	3.8	2.5	2.5	3.8
2nd post-WS-trial	3.8	0.0	3.8	6.3
Costs	0.0	2.5	-1.3	-2.5
Three trials				
1st post-WS-trial	3.8	2.5	3.8	6.3
2nd post-WS-trial	3.8	2.5	6.3	3.8
Costs	0.0	0.0	-2.5	2.5
Four trials				
1st post-WS-trial	7.5	1.3	3.8	6.3
2nd post-WS-trial	3.8	1.3	3.8	1.3
Costs	3.7	0.0	0.0	5.0

	Color match task		Form match task	
CWI	Conflict	Non-conflict	Conflict	Non-conflict
One trial				
1st post-WS-trial	12.5	3.8	11.3	11.3
2nd post-WS-trial	13.8	3.8	7.5	6.3
Costs	-1.3	0.0	3.8	5.0
Two trials				
1st post-WS-trial	6.3	5.0	7.5	5.0
2nd post-WS-trial	0.0	1.3	5.0	6.3
Costs	6.3	3.7	2.5	-1.3
Three trials				
1st post-WS-trial	3.8	1.3	5.0	2.5
2nd post-WS-trial	5.0	0.0	3.8	5.0
Costs	-1.2	1.3	1.2	-2.5
Four trials				
1st post-WS-trial	2.5	2.5	3.8	7.5
2nd post-WS-trial	7.5	0.0	3.8	1.3
Costs	-5	2.5	0.0	6.2

Note. The difference between the first and the second post-WS-trial gives the switch costs (%) on conflict blocks, and the restart costs (%) on non-conflict blocks.

Appendix 4B: Accuracy data for Experiment 2 (Cue Presentation Time - 900 ms)

For trials 1 to 8, the main effect of Cue1 was significant, $F(1, 19) = 4.5$, $p < .05$, reflecting fewer errors on the color match task than on the form match task (2.4 % vs. 3.2 %). The significant main effect of Trial position, $F(7, 133) = 2.4$, $p < .05$, resulted from less accurate performance on the first trial of a block than on trials 2 to 8.
For the post-Cue2-trial (i.e. trial 9), two main effects were reliable; Block type, $F(1, 19) = 5.3$, $p < .05$, and Stimulus congruency, $F(1, 19) = 20.2$, $p < .0001$. The main effect of Block type reflected more accurate performance on non-conflict than on conflict blocks (2.1 % vs. 3.8 %). The main effect of Stimulus congruency resulted from more accurate performance on congruent than on incongruent trials 9 (1.0 % vs. 4.8 %).
On conflict blocks, the main effect of Order of execution was reliable, $F(1, 19) = 4.9$, $p < .05$, reflecting less accurate performance on the first post-WS-trial than on the second post-WS-trial (6.3 % vs. 4.4 %).
On non-conflict blocks, none of the main effects or interactions reached significance all p's > .1.

The first table in Appendix 4B shows the error rate (%) in Experiment 2 (Cue Presentation Time - 900 ms) on the post-Cue2-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent	5.0	2.2	2.8	7.5	4.7	2.8
Congruent	1.3	0.6	0.7	1.3	0.9	0.4

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The second table in Appendix 4B shows the error rate (%) in Experiment 2 (Cue Presentation Time - 900 ms), on the first post-WS trial and on the second post-WS-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Cue Warning signal Interval (one, two, three, or four trials), respectively, top panel - when the post-Cue2-trial was incongruent, down panel - when the post-Cue2-trial was congruent

	Color match task		Form match task	
CWI	Conflict	Non-conflict	Conflict	Non-conflict
One trial				
1st post-WS-trial	1.3	1.3	8.8	5.0
2nd post-WS-trial	1.3	3.8	5.0	3.8
Costs	0.0	-2.5	3.8	1.2
Two trials				
1st post-WS-trial	3.8	2.5	6.3	3.8
2nd post-WS-trial	2.5	2.5	3.8	2.5
Costs	1.3	0.0	2.5	1.3
Three trials				
1st post-WS-trial	8.8	1.3	6.3	2.5
2nd post-WS-trial	6.3	2.5	5.0	2.5
Costs	2.5	-1.2	1.3	0.0
Four trials				
1st post-WS-trial	7.5	3.8	6.3	5.0
2nd post-WS-trial	5.0	2.5	5.0	3.8
Costs	2.5	1.3	1.3	1.2

	Color match task		Form match task	
CWI	Conflict	Non-conflict	Conflict	Non-conflict
One trial				
1st post-WS-trial	6.3	1.3	10.0	3.8
2nd post-WS-trial	6.3	3.8	5.0	1.3
Costs	0.0	-2.5	5.0	2.5
Two trials				
1st post-WS-trial	8.8	1.3	7.5	2.5
2nd post-WS-trial	5.0	1.3	3.8	2.5
Costs	3.8	0.0	3.7	0.0
Three trials				
1st post-WS-trial	5.0	1.3	3.8	2.5
2nd post-WS-trial	6.3	2.5	1.3	7.5
Costs	-1.3	-1.2	2.5	-5.0
Four trials				
1st post-WS-trial	7.5	6.3	2.5	2.5
2nd post-WS-trial	5.0	3.8	3.8	2.5
Costs	2.5	2.5	-1.3	0.0

Note. The difference between the first and the second post-WS-trial gives the switch costs (%) on conflict blocks, and the restart costs (%) on non-conflict blocks.

CHAPTER 5

Does cost-free switching between tasks exist?[1]

Abstract

Whether a combination of goal-directed control and stimulus-driven processing can eliminate switch costs was investigated with the Overlapping Cues Paradigm. Two cues appeared in a block of 16 trials indicating which of two tasks (either a color or a form match task) had to be performed. Cue1 appeared at the beginning of a block, and Cue2 after trial 8. Two trials after Cue2 (i.e. after trial 10), a warning signal (WS) appeared. Participants were instructed to perform the task indicated by Cue1 until WS, and after that to perform the task indicated by Cue2. The stimuli were either congruent (the two tasks required the same response) or incongruent (the two tasks required different responses). The main manipulation concerned the trial position at which a congruent stimulus appeared, i.e. either on trial 9, on trial 10, or on trial 11. All other trials within a block were incongruent.

The data showed (1) Switch costs appear irrespective of stimulus congruency of the trials preceding the actual task switch; (2) A congruent trial at the actual task switch eliminates switch costs for the easy (color) task, and even leads to a benefit for the difficult (form) task. These results suggest that the combination of goal-directed control and stimulus-driven processing can promote effortless task switch.

[1] This chapter is almost identical to Bialkova, S. (in revision-b). Does cost-free switching between tasks exist?

Introduction

Human performance is guided by two types of control mechanisms: (1) goal-directed, top-down control, when performance is determined by the current goals of the person, and (2) stimulus-driven, bottom-up processing when performance is determined by an external stimulus irrespective of the goals of the person (e.g., Atkinson & Shiffrin, 1968; Logan, 1985, 2003; MacLeod, 1991; Norman & Shallice, 1986, 2000; Schneider & Shiffrin, 1977; Shallice, 1994; Shiffrin & Schneider, 1977; Stroop, 1935). The present study investigates the interaction between goal-directed and stimulus-driven control in task switching with goals overlapping in time. More specifically, we address the question whether the combination of goal-directed control and stimulus-driven processing can favor an effortless switch.

To provide an answer to this question, we use the Overlapping Cues Paradigm (OCP, see Chapter 2 for a general description). This paradigm gives the opportunity to distinguish two aspects of task switching, the preparation for and the execution of a new task. This contrasts with classical task switching paradigms where the preparation for and the execution of a new task usually take place right before or at the switch trial itself (e.g., Allport, Styles, & Hsieh, 1994; Jersild, 1927; Meiran, 1996, 2000b; Meiran, Chorev, & Sapir, 2000; Monsell, 2003; Rogers & Monsell, 1995; Spector & Biederman, 1976; Sudevan & Taylor, 1987).

Recently, some researchers have tried to separate the preparation for and the execution of a task switch (e.g., see Gopher, Armony, & Greenshpan, 2000; Kleinsorge & Gajewski, 2006; Logan, 2004; Luria & Meiran, 2003, 2006; Sohn & Anderson, 2001; Sohn & Carlson, 2000; Schneider & Logan, 2007). However, switch costs were still present even in these studies.

In the present Chapter 5, we address the question whether cost-free task switching is possible, using the Overlapping Cues Paradigm. More precisely, we ask whether goal-directed control in combination with stimulus-driven processing can lead to an effortless switch. In the OCP, goal-directed control starts to play a role at Cue2 and possibly the trial right after Cue2 (hereafter referred to as post-Cue2-trial). In principle, participants can use Cue2 and possibly the time they spend on the post-Cue2-trial for at least partially implementing the task to be performed after the WS. For conflict blocks, they could thus start to prepare for the upcoming task switch. Whether they actually do so, or whether they just process Cue2 without actually implementing the new upcoming task is an empirical question (e.g., see Logan, 2003, 2004; Logan & Bundesen, 2003, 2004; Schneider & Logan, 2007). To anticipate, it appears that participants do implement the upcoming task on Cue2 and the post-Cue2-trials, at least partially (e.g., Chapters 2 & 3, but see also Kleinsorge & Gajewski, 2006; Mayr & Kliegl, 2003; Monsell & Mizon, 2006).

The main manipulation in Chapter 5 concerns stimulus congruency: congruent stimuli (both tasks require the same response) vs. incongruent stimuli (both tasks require different responses, see also Figure 2.2 in Chapter 2). The question we are primarily interested in is whether a congruent trial right after WS [2] (hereafter referred to as post-WS-trial) reduces switch costs (i.e. the difference between the first and second post-WS-trial on conflict blocks) relative to conflict blocks with an incongruent post-WS-trial, or perhaps even completely eliminates switch costs. Thus, we compare switch costs in conflict blocks with a congruent post-WS-trial (all other trials being incongruent) with switch costs in conflict blocks with an incongruent post-WS-trial (i.e. all trials in the block being incongruent).

[2] In the present experiments, the interval between Cue2 and Warning signal was fixed on two trials, based on the results from Chapter 4.

However, stimulus-driven processes might not only play a role at the actual task switch, i.e. at the post-WS-trial, but they might also play a role before the actual task switch. A congruent stimulus before the WS might lead to a better establishing of the new upcoming task, and thus might also contribute to a potential reduction of switch costs. In order to address this issue, we added two further conditions in which either the post-Cue2 trial or the next trial was congruent. Again, the question is whether the presence of a congruent stimulus (now at positions before the actual switch trial) reduces switch costs relative to a condition with only incongruent stimuli.

Some researchers (e.g., Meiran & Daichman, 2005; Yehene, Meiran, & Soroker, 2005) argued that the manipulation of stimulus in-/congruency may not provide an appropriate test for the elimination of switch costs because in congruent trials participants occasionally execute the now irrelevant task. It appears that on the congruent post-WS-trial participants actually execute the now relevant task (see the post-hoc analyses reported in the discussions of Experiments 1 and 2). Thus, manipulation of stimulus in-/congruency could be considered as an appropriate candidate to test for the elimination of switch costs.

In sum, in the present experiments, we manipulate the presence or absence of a congruent trial, and thus the presence of stimulus-driven effects, at four different levels (see Chapter 2 for the general lay-out of a trial sequence in an experimental block): either the post-Cue2 trial (trial 9) is congruent or incongruent, or the second trial after Cue2 (trial 10), or the post-WS trial (trial 11), with all other trials in a block being incongruent. In addition to these three types of blocks with a congruent trial, there were also blocks with exclusively incongruent trials.

With this experimental scenario, we can look at the following aspects of the preparation for and the actual execution of a task switch. On the post-Cue2 trial, participants can (start to) load a new task goal in the case of a conflict block while still performing the old task that was indicated by Cue1. The processing costs that are associated with this preparation for a new upcoming task should be reflected in a RT difference between the conflict blocks and the non-conflict blocks at the post-Cue2 trial, a difference we will refer to as transition costs. These transition costs could be modulated by the other two relevant factors at the post-Cue2-trial, the task difficulty on the one hand (easy color match task vs. difficult form match task) and the in-/congruency of the post-Cue2-trial on the other hand. To test whether the preparation for a task switch is completed at the post-Cue2-trial or whether it extends even farther, the same questions will also be addressed for the trial following the post-Cue2 trial (i.e. trial 10).

To investigate whether goal-directed control in combination with stimulus-driven processing can promote an effortless task switch, we explore the effect of stimulus congruency from two different perspectives at the actual task switch. On the one hand, we examine whether a congruent post-WS-trial eliminates switch costs. On the other hand, we examine whether the in-/congruency of the trials intervening between Cue2 and WS (i.e. trials 9 and 10) modulates switch costs.

Finally, the Overlapping Cues Paradigm enables a separate evaluation of the restart costs (difference between the first and second post-WS-trial on non-conflict blocks, e.g., Allport & Wylie, 2000; Gopher et al. 2000; Monsell, 2003). We examine whether restart costs can be eliminated as a function of the trial position at which a congruent stimulus is presented.

We report two experiments. In Experiment 1, Cue1, Cue2, and WS appeared for 200 ms (i.e. Cue Presentation Time (CPT) was fixed at 200 ms). In Experiment 2, CPT was prolonged to 900 ms, i.e. to an interval at which, in standard task switch experiments, so-called residual switch costs are observed (e.g., Allport et al., 1994; De Jong, 2000; Meiran, 1996, 2000a; Meiran et al., 2000; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995), that is switch costs that can not be reduced any further by providing participants with even more time before the switch trial.

Experiment 1

Method

Participants

Twenty participants (4 men and 16 women, between the ages of 19 and 35 years) took part in Experiment 1. All had normal or corrected-to-normal vision.

Stimuli

Stimuli consisted of a reference figure and four match figures (see Figure 2.2 in Chapter 2). Stimuli were either incongruent (the reference figure and the correct match figure had either the same color or the same form) or congruent (the reference figure and the correct match figure had both, the same color and the same form). Congruent stimuli were displayed either on trial 9 (the post-Cue2-trial), on trial 10, or on trial 11 (the post-WS-trial). All other trials within a block were incongruent. In a fourth condition, all trials within a block were incongruent.

Design

There were 128 experimental blocks, each consisting of 16 trials. Presentation order of the blocks was random. There were 16 experimental conditions resulting from the full crossing of three within-participants factors: Cue1 with levels Color and Form, Cue2 with levels Color and Form, and Stimulus congruency with levels Incongruent trials (i.e. no congruent trials occurred in the block), Congruent trial 9, Congruent trial 10, and Congruent trial 11. In the latter three cases, the remaining 15 trials in a block were all incongruent. Each of the 16 conditions was realized by 8 blocks.

Before the experiment there was a short warming-up session consisting of 6 practice blocks. These blocks were excluded from the data analysis.

Procedure

The two tasks (color and form match) were organized in blocks of 16 trials. Two cues indicated which of the tasks has to be performed. The cues were the Dutch words “KLEUR” (“COLOR”) for matching based on color or the word “VORM” (“FORM”) for matching based on form.

Each block began with the word “START” (displayed on the computer screen for 1000 ms), followed by Cue1. Cue Presentation Time for Cue1 (as well as for Cue2 and WS) was 200 ms. One hundred milliseconds after Cue1 a series of 8 trials was presented. The interval from response to trial n to onset of the stimulus for trial n+1 was 100 ms. Two hundred milliseconds after the response on trial 8 a new cue, Cue2 appeared. Cue2 was either different from Cue1 (conflict condition) or the same as Cue1 (non-conflict condition). Two trials after Cue2 (i.e. after trial 10), a star appeared as a warning signal (WS). Participants were instructed to perform the task indicated by Cue1 until WS and after that to perform the task indicated by Cue2. Thus, WS required a task switch in the conflict but not in the non-conflict condition. After the last response of the block (i.e. response to trial 16), a new block started with the word “START” displayed on the screen.

Participants were asked to respond as fast and as accurately as possible with two fingers (index and middle finger) of each hand on a button box with four buttons, which were used to indicate the location of the correct match figure. Feedback asking for faster responding was given if participants did not respond within 2000 ms.

Results

Reaction time (RT) was recorded for all 16 trials of each block. Incorrect responses and out- of- time- responses (trials with RT longer than 2000 ms) were also recorded.

Reaction times. For trials 1 to 8, a repeated measures analysis of variance (ANOVA) was conducted with the factors: Cue1 (Color or Form), Cue2 (Color or Form), Stimulus congruency (Incongruent trials, Congruent trial 9, Congruent trial 10, or Congruent trial 11), and Trial position (1 to 8). There was a significant main effect of Cue1, $F(1, 19) = 220$, $p < .0001$, reflecting faster responding on the color match task than on the form match task (656 ms vs. 887 ms). The main effect of Trial position was also reliable, $F(7, 133) = 22.7$, $p < .0001$, and resulted from slower performance on the first trial of a block than on trials 2 to 8. None of the other main effects or interactions reached significance. These results are in accordance with what one should expect, because potential effects of Cue2 and Stimulus congruency can only show up after trial 8.

RTs for trial 9, the post-Cue2-trial, were analyzed with an ANOVA with the factors: Actual task performed (Color or Form), Block type (Conflict or Non-conflict), and Stimulus congruency (Incongruent[3] or Congruent trial 9). Table 5.1 shows the RTs for trial 9.

Table 5.1

Mean RT (ms) in Experiment 1 (Cue Presentation Time - 200 ms) on the post-Cue2-trial (trial 9) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent). Standard errors of the mean in parentheses

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent	995 (32)	767 (28)	228	1190 (41)	1038 (27)	152
Congruent	919 (31)	732 (26)	187	1028 (43)	860 (34)	168

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

[3] The level "Incongruent trial 9" takes together the conditions with exclusively incongruent trials and with congruent trials on trial 10 or 11. This was done because congruency on trial 10 or 11 can not play a role for performance on trial 9.

The three main effects reached significance. The main effect of Actual task performed, $F(1, 19) = 59$, $p < .0001$, reflected faster performance on the color match task than on the form match task (853 ms vs. 1029 ms). The main effect of Block type, $F(1, 19) = 123$, $p < .0001$, resulted from slower performance on conflict than on non-conflict blocks (1033 ms vs. 849 ms). This time difference reflected 184 ms transition costs. Although descriptively, transition costs were higher when implementing the form match task while doing the color match task than for the reverse situation (see Table 5.1), the two-way interaction Actual task performed by Block type was not reliable ($p > .1$). Two separate analyses, for incongruent and congruent trials, respectively, show that the interaction Actual task performed by Block type was significant in case of an incongruent post-Cue2-trial ($p < .05$), but not in case of a congruent post-Cue2-trial ($p > .6$).

Furthermore, the main effect of Stimulus congruency, $F(1, 19) = 90$, $p < .0001$, reflected faster responding when the post-Cue2-trial was congruent (885 ms) than when it was incongruent (998 ms). Performance was affected more by stimulus congruency when the actual task performed was the form match task than when it was the color match task. This resulted in a reliable two-way interaction of Actual task performed and Stimulus congruency, $F(1, 19) = 33$, $p < .0001$. Neither the interaction of Block type and Stimulus congruency ($p > .7$), nor the triple interaction of Actual task performed, Block type, and Stimulus congruency ($p > .3$) were significant.

For the second trial after Cue2 (trial 10), the same analytical procedure was used as for the post-Cue2-trial (trial 9) with one exception. Now the factor Stimulus congruency has three levels: incongruent trials[4], incongruent trial 10 preceded by a congruent trial 9, and congruent trial 10 preceded by incongruent trials. In Table 5.2,

[4] The level "Incongruent trials" takes together the condition with exclusively incongruent trials and the condition with a congruent trial 11. This was done because congruency on trial 11 can not play a role for performance on trial 10.

the mean RT (ms) on trial 10 is presented as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent trial 9, congruent trial 10).

Table 5.2

Mean RT (ms) in Experiment 1 (Cue Presentation Time - 200 ms) on the second trial after Cue2 (trial 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent trial 9, congruent trial 10). Standard errors of the mean in parentheses

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent trials	744 (22)	636 (14)	108	996 (25)	897 (26)	99
Congruent 9	766 (35)	659 (19)	107	1029 (34)	972 (36)	57
Congruent 10	684 (20)	644 (19)	40	885 (25)	790 (26)	95

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

Responding was faster on the color match task than on the form match task (689 ms vs. 928 ms), as reflected in a main effect of Actual task performed, $F(1, 19) = 203$, $p < .0001$. Participants were slower on conflict than on non-conflict blocks (851 ms vs. 766 ms, 85 ms transition costs), yielding a main effect of Block type, $F(1, 19) = 82$, $p < .0001$. Transition costs were not significantly modulated by task difficulty, as indicated by the non-significant interaction of Actual task performed and Block type, $p > .9$. The main effect of stimulus congruency was reliable, $F(2, 38) = 36$, $p < .0001$. Performance was fastest on a congruent trial 10 preceded by incongruent trials (lowest line in Table 5.2, average RT = 751 ms), and slowest on an incongruent trial 10 preceded by a congruent trial 9 (middle line in Table 5.2, average RT = 856 ms). On an incongruent trial 10 preceded by incongruent trials, the average RT was 818 ms (top line in Table 5.2). The two-way interaction of Actual task performed and Stimulus congruency was also significant, $F(2, 38) = 13$, $p < .0001$, reflecting the fact that stimulus congruency had a larger impact on performance in the form match task than in the color match task.

On conflict blocks, for the first and second post-WS-trial (i.e. trials 11 and 12) an ANOVA was conducted with the factors: Actual task performed (Color or Form), Order of execution (First vs. Second post-WS-trial), and Stimulus congruency (Incongruent trials, Congruent post-Cue2-trial, Congruent pre-WS-trial, or Congruent post-WS-trial). Table 5.3 gives the mean RTs and the performance costs for the first and second post-WS-trial.

Table 5.3

Mean RT (ms) in Experiment 1 (Cue Presentation Time - 200 ms) on the first and second post-WS-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, congruent post-WS-trial). Standard errors of the mean in parentheses

	Color match task		Form match task	
Congruency	Conflict	Non-conflict	Conflict	Non-conflict
Incongruent trials				
1st post-WS-trial	788 (27)	655 (21)	981 (44)	925 (34)
2nd post-WS-trial	671 (21)	620 (19)	883 (38)	868 (29)
Costs	117	35	98	57
Congruent post-Cue2-trial				
1st post-WS-trial	831 (35)	681 (18)	977 (37)	909 (32)
2nd post-WS-trial	676 (34)	657 (19)	894 (35)	876 (34)
Costs	155	24	83	33
Congruent pre-WS-trial				
1st post-WS-trial	792 (30)	705 (24)	983 (29)	994 (33)
2nd post-WS-trial	649 (22)	659 (21)	885 (25)	889 (25)
Costs	143	46	98	105
Congruent post-WS-trial				
1st post-WS-trial	722 (27)	643 (19)	870 (32)	788 (27)
2nd post-WS-trial	702 (33)	681 (25)	1013 (47)	921 (32)
Costs	20	-38	-143	-133

Note. The difference between the first and the second post-WS-trial gives the switch costs (ms) on conflict blocks, and the restart costs (ms) on non-conflict blocks.

The analysis revealed significant main effects of Actual task performed, $F(1, 19) = 119$, $p < .0001$, and of Order of execution, $F(1, 19) = 16.7$, $p < .001$. The main effect of Stimulus congruency was not reliable, $p > .6$. The main effect of Actual task performed resulted from faster responding on the color match task than on the form match task. The main effect of Order of execution reflected slower performance on the first than on the second post-WS-trial, and thus, switch costs. Switch costs were modulated by Stimulus congruency, resulting in a significant two-way interaction between Order of execution and Stimulus congruency, $F(3, 57) = 26.6$, $p < .0001$.

Switch costs were eliminated when the post-WS-trial was congruent. By contrast, when the post-WS-trial was incongruent, there were switch costs, and these costs appeared irrespective of stimulus congruency of the trials preceding WS. The interaction between Actual task performed and Order of execution also reached significance, $F(1, 19) = 14$, $p < .001$. A closer look at the results shows that when the post-WS-trial was incongruent, switch costs were higher for the switch from the difficult (form match) task to the easy (color match) task than in the opposite direction. When the post-WS-trial was congruent, switch costs were reduced for the switch from form to color (20 ms), and switch costs turned into a switch gain for the switch from color to form (-143 ms). These last findings were reflected in a marginally reliable triple interaction between Order of execution, Actual task performed, and Stimulus congruency, $F(3, 57) = 2.7$, $p = .056$.

On non-conflict blocks, for the first and second post-WS-trial (i.e. trials 11 and 12), an ANOVA was run with the same factors as for the first and second post-WS-trial on conflict blocks; Actual task performed (Color or Form), Order of execution (First vs. Second post-WS-trial), and Stimulus congruency (Incongruent trials, Congruent post-Cue2-trial, Congruent pre-WS-trial, or Congruent post-WS-trial). Two main effects were significant; Actual task performed, $F(1, 19) = 237$, $p < .0001$, and Stimulus congruency, $F(3, 57) = 4.6$, $p < .01$. Participants were faster on the color match task than on the form match task, resulting in a main effect of Actual task performed. The main effect of Stimulus congruency resulted from relatively slow performance when the pre-WS-trial was congruent. The main effect of Order of execution (reflecting potential restart costs) was not reliable, $p > .2$. However, the two-way interaction between Order of execution and Stimulus congruency was reliable, $F(3, 57) = 19$, $p < .0001$, reflecting an asymmetry in restart costs with respect to stimulus congruency. The two-way interaction between Actual task performed and Stimulus congruency, $F(3, 57) = 2.8$, $p < .05$, and the three-way interaction between Order of execution, Actual task performed, and Stimulus congruency, $F(3, 57) = 4$, $p < .01$, were also reliable. This reflected the fact that restart costs turned into a restart gain when the post-WS-trial was congruent. By contrast, when the post-WS-trial was incongruent, there were restart costs. On the color match task, restart costs appeared irrespective of stimulus congruency of the trials preceding WS, while on the form match task, restart costs were highest when the pre-WS-trial was congruent.

Error rate. For errors, the same analytical procedure as for reaction times was used. Overall, the pattern of errors followed the pattern of reaction times. The descriptive error data and the corresponding statistical analyses are presented in Appendix 5A.

Discussion

The results show that a specific combination of goal-directed control and stimulus-driven processing can lead to an effortless switch. More precisely, when the post-WS-trial is congruent, switch costs are reduced on the color match task, and switch costs even turned into a switch benefit on the form match task.

What do participants actually do at a congruent post-WS-trial? There appear to be two possible scenarios. In the first scenario, participants do not switch at all when the switch trial (i.e. the post-WS-trial) is congruent, but rather postpone the switch to the next trial. If this is the case, one should see switch costs at the two trials following the first post-WS-trial, i.e. in a comparison of the second and third post-WS-trial. In the second scenario, participants do switch at the first post-WS-trial, but this switch is not associated with costs or even associated with a gain when the trial is congruent. If this is the case, there should be no difference in performance between the second and third post-WS-trial. In order to test these scenarios, an additional ANOVA encompassing the second and third post-WS-trial was run. Neither the main effect of Order of execution, nor any interactions reached significance, all p's > .1 (for the descriptive results see Table 5.4).

Table 5.4

Difference in performance (ms) between the second and third post-WS-trial on conflict blocks in Experiment 1 (Cue Presentation Time - 200 ms) as a function of Actual task performed (color, form) and Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, congruent post-WS-trial)

Congruency	Color match task	Form match task
Incongruent trials	11	1
Congruent post-Cue2-trial	9	7
Congruent pre-WS-trial	-23	18
Congruent post-WS-trial	17	84

Descriptively, on the form match task with a congruent post-WS-trial, performance was 84 ms slower on the second than on the third post-WS-trial. However, this result was not substantiated statistically, as revealed by a separate ANOVA for the form match task (Order of execution by Stimulus congruency, $p > .1$). Thus, it seems that participants do switch at a congruent post-WS-trial, but that this switch does not incur switch costs (in case of the switch to the easy color task) or even leads to a switch benefit (in case of the switch to the difficult form task). It appears that the combination of a top-down factor, the preparation for an upcoming task switch at the post-Cue2-trial, and a bottom-up factor, stimulus congruency on the actual switch trial, can completely eliminate switch costs or even leads to a switch gain.

By contrast, when the post-WS-trial was incongruent, there were switch costs. Although descriptively, switch costs were higher for the switch from the more difficult task to the easier task than in the opposite direction this result was not substantiated statistically. More important in the present context, switch costs were independent of the stimulus congruency of the trials intervening between Cue2 and WS.

When we turn to the trials intervening between Cue2 and WS, we see that transition costs also appeared irrespective of stimulus congruency. Thus, the task indicated by Cue2, seems to be loaded on a higher, more abstract level than an implicit response execution induced by congruent stimuli. However, stimulus congruency had some effect on performance. On the post-Cue2-trial, performance was faster when this trial was congruent than when it was incongruent. This was presumably due to stimulus-driven processing at a congruent post-Cue2-trial. If this is the case, on the next trial, the irrelevant task has to be suppressed on non-conflict blocks, which results in a slow-down in performance. This hypothesis was supported by the results. On the second trial after Cue2, performance was slowest on an incongruent trial preceded by a congruent post-Cue2-trial, and fastest on a congruent trial preceded by incongruent trials. Furthermore, congruency had an effect on the actual task performed. The difference in performance between congruent and incongruent trials (preceded by incongruent trials) was higher on the more difficult task than on the easier task.

Finally, on non-conflict blocks, restart costs appeared when the post-WS-trial was incongruent. These costs were highest when the pre-WS-trial was congruent, which is presumably due to activation of the irrelevant task in a stimulus-driven manner via a congruent pre-WS-trial. By contrast, when the post-WS-trial was congruent, restart costs turned into restart gains. It could be the case, however, that these restart gains do not reflect actual gains at the post-WS-trial, but are rather due to especially long RTs at the trials following the post-WS-trial. This could be the case if the irrelevant task is activated in a stimulus-driven manner by a congruent post-WS-trial. This activation of the irrelevant task has to be suppressed on the trial following the post-WS-trial, which leads to a slow-down in performance on this trial relative to the post-WS-trial. This scenario would predict that performance should be slower at the second than at the third post-WS-trial. A corresponding additional analysis of the second and third post-WS-trial did not show a main effect of Order of execution, nor any interactions, all p's > .05 (for the descriptive results see Table 5.5). This result clearly suggests that we are indeed dealing with genuine facilitation of a task restart in the case of a congruent post-WS-trial.

Table 5.5

Difference in performance (ms) between the second and third post-WS-trial on non-conflict blocks in Experiment 1 (Cue Presentation Time - 200 ms) as a function of Actual task performed (color, form) and Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, congruent post-WS-trial)

Congruency	Color match task	Form match task
Incongruent trials	10	7
Congruent post-Cue2-trial	20	27
Congruent pre-WS-trial	36	0
Congruent post-WS-trial	16	22

In sum, stimulus congruency had a clear effect on the actual execution of a task switch, i.e. at the post-WS-trial, while it did not statistically affect the preparation for the task switch, i.e. at the trials intervening between Cue2 and WS. Most notably, the combination of top-down control (implementation of the goal for an upcoming new task at the post-Cue2-trial) with a bottom-up effect of a congruent post-WS-trial (i.e. a congruent switch trial) eliminates any switch costs or even turns them into a switch benefit. This strongly suggests that task switches can be performed without any costs (or even with a gain) with an appropriate combination of top-down and bottom-up influences.

There is, however, one caveat concerning this conclusion. In one of the conditions (form match task, and congruent post-WS-trial) the descriptive data show a 84 ms difference between the second and third post-WS-trials. Although this difference was not statistically significant, one could ask what the reason for this difference is. A possible explanation could be that participants need extra time to suppress the irrelevant task. To test whether this was the case, we replicated Experiment 1, but now with a longer cue presentation time. The critical question is whether an effortless switch can only be obtained with congruent switch trials, or whether a long cue presentation time also allows for an effortless switch for incongruent switch trials.

Experiment 2

Experiment 2 is a replication of Experiment 1 with only one change: In Experiment 2, Cue Presentation Time was fixed at 900 ms. This time interval was chosen because it is in the range of the time interval at which, in standard task switch studies, no further reduction of so-called residual switch costs is observed (e.g., Allport et al., 1994; De Jong, 2000; Meiran, 1996, 2000a; Meiran et al., 2000; Monsell et al., 2000; Rogers & Monsell, 1995).

Method

Participants. Twenty participants (4 men and 16 women, between the ages of 20 and 28 years) took part in Experiment 2. All had normal or corrected-to-normal vision.

Stimuli, Design, and Procedure were the same as in Experiment 1. There was only one difference: In Experiment 2, the presentation time for Cue1, Cue2, and WS was fixed at 900 ms.

Results

The same analytical procedure as in Experiment 1 was used.

The ANOVA for trials 1 to 8 revealed significant main effects of Cue1 $F(1, 19) = 421$, $p < .0001$, and of Trial position, $F(7, 133) = 38.2$, $p < .0001$. Performance was faster on the color match task than on the form match task (658 ms vs. 865 ms), and slower on the first trial of a block than on trials 2 to 8. None of the other main effects or interactions were significant.

For the post-Cue2-trial (i.e. trial 9), the relevant analysis showed that all main effects were significant; Actual task performed, Block type, and Stimulus congruency. RTs and transition costs on the post-Cue2-trial are shown in Table 5.6.

Table 5.6

Mean RT (ms) in Experiment 2 (Cue Presentation Time - 900 ms) on the post-Cue2-trial (trial 9) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent). Standard errors of the mean in parentheses

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent	771 (25)	687 (23)	84	956 (27)	870 (26)	86
Congruent	722 (26)	623 (26)	99	878 (34)	811 (34)	67

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

The main effect of Actual task performed, $F(1, 19) = 115$, $p < .0001$, resulted from faster responding on the color match task than on the form match task (701 ms vs. 879 ms). The main effect of Block type, $F(1, 19) = 26.5$, $p < .0001$, reflected slower performance on a conflict block than on a non-conflict block (832 ms vs. 748 ms), and thus, 84 ms transition costs. The main effect of Stimulus congruency, $F(1, 19) = 22.7$, $p < .0001$, resulted from faster performance when the post-Cue2-trial was congruent than when it was incongruent (759 ms vs. 822 ms). None of the interactions reached significance (all p's > .1).

In Table 5.7, RTs and transition costs on the second trial after Cue2 (i.e. trial 10) are presented.

Table 5.7

Mean RT (ms) in Experiment 2 (Cue Presentation Time - 900 ms) on the second trial after Cue2 (trial 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent trial 9, congruent trial 10). Standard errors of the mean in parentheses

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent trials	681 (20)	640 (16)	41	895 (23)	848 (21)	47
Congruent 9	726 (31)	647 (24)	79	923 (26)	920 (39)	3
Congruent 10	659 (23)	618 (21)	41	825 (18)	767 (26)	58

Note. The difference between conflict and non-conflict blocks gives the transition costs (ms).

For trial 10, the three main effects were significant. Participants needed less time to perform the color match task than the form match task (662 ms vs. 863 ms), resulting in a main effect of Actual task performed, $F(1, 19) = 423$, $p < .0001$. Responding was slower on conflict than on non-conflict blocks (785 ms vs. 740 ms), resulting in a main effect of Block type, $F(1, 19) = 24$, $p < .0001$. Performance was fastest on a congruent trial 10 preceded by incongruent trials (717 ms), and slowest on an incongruent trial 10 preceded by a congruent trial 9 (804 ms). On an incongruent trial 10 preceded by incongruent trials, the mean RT was 766 ms. These last findings yielded a significant main effect of Stimulus congruency, $F(2, 38) = 15$, $p < .0001$. Stimulus congruency interacted with Actual task performed, resulting in a reliable two-way interaction, $F(2, 38) = 9.1$, $p < .001$. Performance was less sensitive to stimulus congruency on the color match task than on the form match task. None of the other interactions reached significance, all p's > .05.

The next analyses concern performance after WS. In Table 5.8, RTs and performance costs on the first and second post-WS-trial (i.e. trials 11 and 12) are shown.

Table 5.8

Mean RT (ms) in Experiment 2 (Cue Presentation Time - 900 ms) on the first and second post-WS-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, congruent post-WS-trial). Standard errors of the mean in parentheses

	Color match task		Form match task	
Congruency	Conflict	Non-conflict	Conflict	Non-conflict
Incongruent trials				
1st post-WS-trial	795 (30)	624 (24)	977 (27)	814 (27)
2nd post-WS-trial	665 (24)	592 (15)	838 (24)	818 (20)
Costs	130	32	139	-4
Congruent post-Cue2-trial				
1st post-WS-trial	837 (38)	635 (35)	994 (35)	856 (35)
2nd post-WS-trial	657 (19)	623 (20)	861 (23)	831 (26)
Costs	180	12	133	25
Congruent pre-WS-trial				
1st post-WS-trial	803 (39)	668 (28)	939 (30)	884 (37)
2nd post-WS-trial	650 (27)	624 (22)	851 (27)	856 (34)
Costs	153	44	88	28
Congruent post-WS-trial				
1st post-WS-trial	737 (33)	625 (23)	841 (31)	798 (29)
2nd post-WS-trial	713 (42)	652 (23)	947 (36)	903 (26)
Costs	24	-27	-106	-105

Note. The difference between the first and the second post-WS-trial gives the switch costs (ms) on conflict blocks, and the restart costs (ms) on non-conflict blocks.

On conflict blocks, for the first and second post-WS-trial, an ANOVA was run with the factors Actual task performed (Color or Form), Order of execution (First vs. Second post-WS-trial), and Stimulus congruency (Incongruent trials, Congruent post-Cue2-trial, Congruent pre-WS-trial, or Congruent post-WS-trial). The main effects of Actual task performed, $F(1, 19) = 111$, $p < .0001$, and of Order of execution, $F(1, 19) = 39$, $p < .0001$ were significant. The main effect of Stimulus congruency was not reliable, $p > .1$. Responding was faster on the color match task than on the form match task, resulting in a main effect of Actual task performed. The main effect of Order of execution reflected switch costs. Switch costs were asymmetric with respect to stimulus congruency, resulting in a significant interaction between Order of execution and Stimulus congruency, $F(3, 57) = 17$, $p < .0001$. When the post-WS-trial was congruent, switch costs were eliminated. Conversely, when the post-WS-trial was incongruent, there were switch costs. These costs appeared irrespective of stimulus congruency of the trials preceding WS. The two-way interaction between Actual task performed and Order of execution was reliable, $F(1, 19) = 4.5$, $p < .05$. A closer look at the results shows that when the post-WS-trial was congruent, switch costs were reduced for the switch from form to color (24 ms), and switch costs turned into a switch benefit for the switch from color to form (-106 ms). When the post-WS-trial was incongruent and congruent stimuli appeared on the post-Cue2-trial or on the pre-WS-trial, switch costs were higher for the switch from form to color than in the opposite direction. When all trials were incongruent, switch costs appeared irrespective of task difficulty (for details, see Table 5.8). This pattern resulted in a marginally significant triple interaction between Actual task performed, Order of execution, and Stimulus congruency, $F(3, 57) = 2.5$, $p = .072$.

On non-conflict blocks, the relevant ANOVA showed significant main effects of Actual task performed, $F(1, 19) = 348$, $p < .0001$, and of Stimulus congruency, $F(3, 57) = 4.5$ $p < .01$. The main effect of Order of execution was not reliable, $p > .9$. However, the interaction between Order of execution and Stimulus congruency was reliable, $F(3, 57) = 6.4$, $p < .001$. When the post-WS-trial was incongruent, relatively small restart costs were obtained. When the post-WS-trial was congruent, these restart costs turned into a restart gain. None of the other interactions was reliable, all p‘s > .1.

Overall, the results of errors followed those for reaction times (see Appendix 5B).

Discussion

Although in Experiment 2 the prolonged Cue Presentation Time (CPT) of 900 ms increased the time available for processing Cue2 and WS, evidence for an effortless switch was again (as in Experiment 1) only obtained when the actual switch trial was congruent.

On conflict blocks, when the actual switch trial (i.e. first post-WS-trial) was congruent, switch costs were reduced for the switch from form to color and switch costs turned into a switch benefit for the switch from color to form. As in Experiment 1, an additional ANOVA was done for the second and third post-WS-trial. Neither the main effect of Order of execution, nor any interactions were significant, all *p*'s > .05 (see Table 5.9 for the descriptive results). This indicates that, as in Experiment 1, when the actual switch trial is congruent, participants do not delay the task switch to a later trial.

Table 5.9

Difference in performance (ms) between the second and third post-WS-trial on conflict blocks in Experiment 2 (Cue Presentation Time - 900 ms) as a function of Actual task performed (color, form) and Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, congruent post-WS-trial)

Congruency	Color match task	Form match task
Incongruent trials	17	-34
Congruent post-Cue2-trial	-11	-12
Congruent pre-WS-trial	-12	12
Congruent post-WS-trial	35	48

Conversely, when the post-WS-trial was incongruent, there were switch costs. These costs did not differ with respect to task difficulty or with respect to stimulus congruency of the trials intervening between Cue2 and WS.

When we look at the trials intervening between Cue2 and WS, we see that transition costs also appeared irrespective of task difficulty and irrespective of stimulus congruency. However, on the post-Cue2-trial, performance was faster when the trial was congruent than when it was incongruent. The same held for the second trial after

Cue2. These findings suggest that the irrelevant task is not completely silent during the interval between Cue2 and WS. Rather, the irrelevant task seems to receive additional activation in a stimulus-driven manner via a congruent trial.

Finally, on non-conflict blocks, descriptive restart costs turned into restart gains when the post-WS-trial was congruent. The additional analysis for the second and third post-WS-trial showed no main effect of Order of execution (p > .1). None of the interactions was significant (all p's > .1) except the interaction between Order of execution and Stimulus congruency, $F(3, 57) = 4.1$, $p < .01$. When the post-WS-trial was congruent, performance was slower on the second than on the third post-WS-trial (see Table 5.10).

Table 5.10

Difference in performance (ms) between the second and third post-WS-trial on non-conflict blocks in Experiment 2 (Cue Presentation Time - 900 ms) as a function of Actual task performed (color, form) and Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, congruent post-WS-trial)

Congruency	Color match task	Form match task
Incongruent trials	-18	-2
Congruent post-Cue2-trial	1	-22
Congruent pre-WS-trial	27	15
Congruent post-WS-trial	20	79

This pattern can be explained by assuming that on non-conflict blocks, the irrelevant task is activated in a stimulus-driven manner via a congruent post-WS-trial. On the next trial, this activation of the irrelevant task has to be suppressed in a top-down manner, which results in longer reaction times.

To summarize, although the time for processing a task at Cue2 and WS was prolonged (CPT 900 ms), the elimination of switch costs for the easy (color) task and the switch benefit for the difficult (form) task were only obtained in the case when the actual switch trial, i.e. the post-WS-trial, was congruent. By contrast, prolonged CPT led to reduction of restart costs when the post-WS-trial was incongruent, and restart costs turned into restart gains when the post-WS-trial was congruent.

General discussion

The present study investigated whether the combination of top-down, goal-directed control and bottom-up, stimulus-driven processing can lead to an effortless task switch. The main question addressed was: Can early goal-directed control together with stimulus-driven processing at the actual task switch reduce or perhaps even eliminate switch costs? In addition we asked whether stimulus-driven processing plays only a role at the switch trial itself or also during the preparation for a task switch.

To answer these questions, the Overlapping Cues Paradigm was used as an experimental tool. The main manipulation concerned the presentation of congruent stimuli (both tasks require the same response) either during the preparation for a switch or at the actual switch. This contrasts with previous studies where the stimulus congruency was manipulated primarily at the switch trial itself (e.g., Goschke, 2000; Hunt & Klein, 2002; Kleinsorge & Gajewski, 2006; Koch & Allport, 2006; Meiran, 2000b; Rogers & Monsell, 1995; Ruthruff, Remington & Johnston, 2001; Wylie & Allport, 2000; Yeung & Monsell, 2003).

The results from the present study show that an adequate constellation of goal-directed control and stimulus-driven processing can lead to an effortless switch. More specifically, when congruent stimuli appeared at the actual task switch, switch costs were reduced for the switch from form to color, and switch costs turned into a switch benefit for the switch from color to form (see Figure 5.1). This effect was present irrespective of CPT. This latter conclusion is supported by a cross-experiment ANOVA in which none of the interactions of CPT with other factors reached significance, all *p*'s > .1.

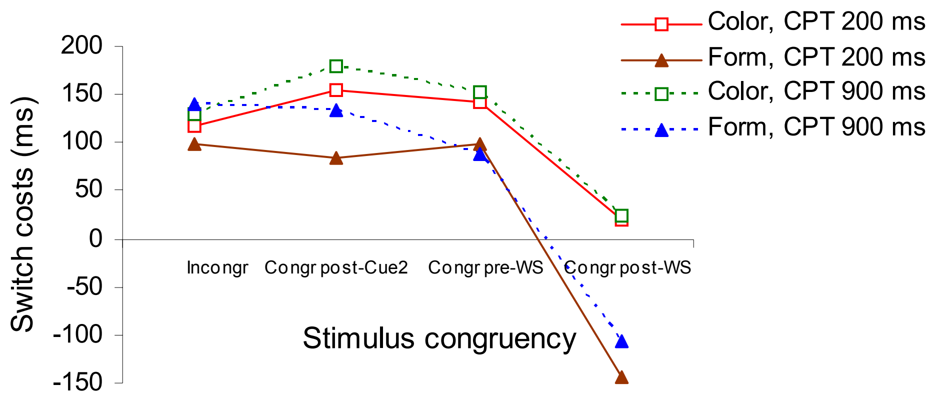

Figure 5.1. Switch costs (ms) in Experiment 1 (Cue Presentation Time - 200 ms) and in Experiment 2 (Cue Presentation Time - 900 ms) as a function of Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, and congruent post-WS-trial) and Actual task performed (color or form).

When incongruent stimuli were presented at the actual task switch, switch costs did not differ with respect to task difficulty or with respect to stimulus congruency of the trials preceding WS. These effects appeared irrespective of CPT as is evident from a separate cross-experiment ANOVA in which none of the interactions of CPT with other factors reached significance, all *p*'s > .3.

In sum, the in-/congruency of the trials preceding WS did not affect switch costs, while the status of the post-WS-trial had a clear effect on switch costs. This fits nicely with previous findings associating switch costs with processing of the stimulus (e.g., Allport & Wylie, 2000; Goschke, 2000; Mayr & Kliegl, 2003; Rogers & Monsell, 1995; Wylie & Allport, 2000; Yeung & Monsell, 2003).

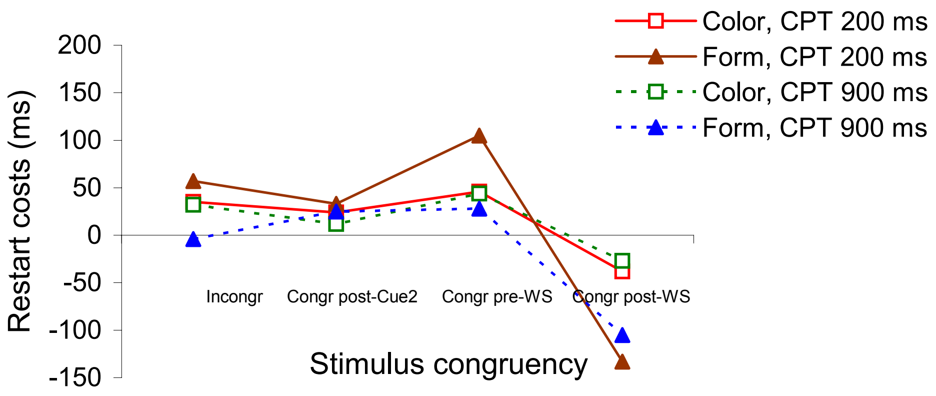

Figure 5.2. Restart costs (ms) in Experiment 1 (Cue Presentation Time - 200 ms) and in Experiment 2 (Cue Presentation Time - 900 ms) as a function of Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, and congruent post-WS-trial) and Actual task performed (color or form).

On non-conflict blocks, when incongruent stimuli were presented on the post-WS-trial, on the color match task, restart costs appeared irrespective of stimulus congruency of the trials preceding WS (see Figure 5.2). By contrast, on the form match task, for short CPT, restart costs were highest when the pre-WS-trial was congruent.

Furthermore, when congruent stimuli were presented on the post-WS-trial, restart costs turned into a restart gain, with a larger restart gain on the form match task than on the color match task.

To conclude, the results show that when a new task is introduced while an old task is still being performed, congruent stimuli at the switch trial itself eliminate the switch costs for a relatively easy task and even turn switch costs into switch benefits for a relatively difficult task. Thus, it appears that early top-down, goal-directed control together with bottom-up, stimulus-driven processing at the actual task switch can eliminate any residual switch costs and lead to an effortless task switch.

Appendix 5A: Error data for Experiment 1 (Cue Presentation Time - 200 ms)

For trials 1 to 8, none of the main effects or interactions reached significance.
For trial 9 (i.e. the post-Cue2-trial), three main effects were significant; Actual task performed, $F(1, 19) = 4.8$, $p < .05$; Block type, $F(1, 19) = 7$, $p < .01$; and Stimulus congruency, $F(1, 19) = 29$, $p < .0001$. Participants generated fewer errors on the color match task than on the form match task (5.5 % vs. 8.8 %), fewer errors on non-conflict than on conflict blocks (5.6 % vs. 8.8 %), and fewer errors on a congruent trial 9 than on an incongruent trial 9 (3.9 % vs. 10.4 %). The reliable two-way interaction Block type by Stimulus congruency, $F(1, 19) = 7.8$, $p < .01$, reflected elimination of transition costs on a congruent trial 9.
For trial 10, two main effects reached significance; Actual task performed, $F(1, 19) = 9$, $p < .01$, and Block type, $F(1, 19) = 4.6$, $p < .05$. Performance was more accurate on the color match task than on the form match task (4.6 % vs. 7.6 %), and less accurate on conflict than on non-conflict blocks (7.0 % vs. 5.2 %).
On conflict blocks, only the two-way interaction between Order of execution and Stimulus congruency reached significance, $F(3, 57) = 5.7$, $p < .01$, reflecting elimination of switch costs when the post-WS-trial was congruent.
On non-conflict blocks, the main effect of Actual task performed, $F(1, 19) = 9.2$, $p < .01$, reflected more accurate performance on the color match task than on the form match task (1.6 % vs. 4.9 %). The main effect of Stimulus congruency ($F(3, 57) = 3.9$, $p < .01$), as well as the two-way interaction between Order of execution and Stimulus congruency ($F(3, 57) = 7.2$, $p < .0001$) were reliable. Restart costs turned into a restart gain when a congruent stimulus appeared either on the pre-WS-trial or on the post-WS-trial.

The first table in Appendix 5A shows the error rate (%) in Experiment 1 (Cue Presentation Time - 200 ms) on the post-Cue2-trial (trial 9) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent	10.8	5.0	5.8	15.4	10.4	5.0
Congruent	3.8	2.5	1.3	5.0	4.4	0.6

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The second table in Appendix 5A shows the error rate (%) in Experiment 1 (Cue Presentation Time - 200 ms) on the second trial after Cue2 (trial 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent trial 9, congruent trial 10)

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent trials	7.2	3.8	3.4	10.6	7.5	3.1
Congruent 9	5.0	5.6	-0.6	8.8	4.4	4.4
Congruent 10	3.1	3.1	0.0	7.5	6.9	0.6

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The third table in Appendix 5A shows the error rate (%) in Experiment 1 (Cue Presentation Time - 200 ms) on the first and second post-WS-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, congruent post-WS-trial)

	Color match task		Form match task	
Congruency	Conflict	Non-conflict	Conflict	Non-conflict
Incongruent trials				
1st post-WS-trial	4.4	0.6	7.5	6.9
2nd post-WS-trial	7.5	1.2	6.9	2.5
Costs	-3.1	-0.6	0.6	4.4
Congruent post-Cue2-trial				
1st post-WS-trial	5.6	1.9	8.8	5.0
2nd post-WS-trial	3.7	0.6	6.3	2.5
Costs	1.9	1.3	2.5	2.5
Congruent pre-WS-trial				
1st post-WS-trial	5.6	0.6	6.2	5.6
2nd post-WS-trial	6.3	4.4	2.5	8.8
Costs	-0.7	-3.8	3.7	-3.2
Congruent post-WS-trial				
1st post-WS-trial	1.3	0.6	3.8	0.6
2nd post-WS-trial	6.9	2.5	8.8	7.5
Costs	-5.6	-1.9	-5.0	-6.9

Note. The difference between the first and the second post-WS-trial gives the switch costs (%) on conflict blocks, and the restart costs (%) on non-conflict blocks.

Appendix 5B: Error data for Experiment 2 (Cue Presentation Time - 900 ms)

For trials 1 to 8, two main effects were significant; Cue1 ($F(1, 19) = 6.2$, $p < .05$, reflecting more accurate performance on the color match task than on the form match task) and Trial position ($F(7, 133) = 3.3$, $p < .01$, reflecting less accurate performance on the first trial of a block than on trials 2 to 8).

For trial 9 (i.e. the post-Cue2-trial), there were three significant main effects; Actual task performed, Block type, and Stimulus congruency. The main effect of Actual task performed, $F(1, 19) = 8.4$, $p < .01$, resulted from better performance on the color match task than on the form match task (3.8 % vs. 6.6 %). The main effect of Block type, $F(1, 19) = 15.4$, $p < .001$, reflected less accurate performance on conflict than on non-conflict blocks (6.5 % vs. 3.8 %). Participants generated more errors when trial 9 was incongruent than when it was congruent (7.1 % vs. 3.3 %), as resulted in a reliable main effect of Stimulus congruency, $F(1, 19) = 12.4$, $p < .01$. The two-way interaction Actual task performed by Stimulus congruency was reliable, $F(1, 19) = 4.8$, $p < .05$. This reflected more sensitive performance to stimulus congruency on the form match task than on the color match task.

For trial 10, two main effects were reliable. Performance was more accurate on the color match task than on the form match task (2.7 % vs. 5.3 %), as reflected in a main effect of Actual task performed, $F(1, 19) = 24$, $p < .0001$. The main effect of Stimulus congruency, $F(2, 38) = 4.8$, $p < .01$, reflected fewer errors when trial 10 was congruent than when it was incongruent.

On conflict blocks, the reliable two-way interaction between Order of execution and Stimulus congruency, $F(3, 57) = 9.4$, $p < .0001$, reflected elimination of switch costs when the post-WS-trial was congruent.

On non-conflict blocks, the significant main effect of Actual task performed, $F(1, 19) = 5.8$, $p < .05$, resulted from more accurate performance on the color match task than on the form match task (2.1 % vs. 3.9 %).

The first table in Appendix 5B shows the error rate (%) in Experiment 2 (Cue Presentation Time - 900 ms) on the post-Cue2-trial (trial 9) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency on the post-Cue2-trial (incongruent, congruent)

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent	5.8	2.9	2.9	12.7	6.9	5.8
Congruent	3.8	2.5	1.3	3.8	3.1	0.7

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The second table in Appendix 5B shows the error rate (%) in Experiment 2 (Cue Presentation Time - 900 ms) on the second trial after Cue2 (trial 10) as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent trial 9, congruent trial 10)

	Color match task			Form match task		
Congruency	Conflict	Non-conflict	Costs	Conflict	Non-conflict	Costs
Incongruent trials	5.3	3.4	1.9	7.8	4.1	3.7
Congruent 9	2.5	2.5	0.0	8.1	5.0	3.1
Congruent 10	0.0	2.5	-2.5	4.4	2.5	1.9

Note. The difference between conflict and non-conflict blocks gives the transition costs (%).

The third table in Appendix 5B shows the error rate (%) in Experiment 2 (Cue Presentation Time - 900 ms) on the first and second post-WS-trial as a function of Actual task performed (color, form), Block type (conflict, non-conflict), and Stimulus congruency (incongruent trials, congruent post-Cue2-trial, congruent pre-WS-trial, congruent post-WS-trial)

	Color match task		Form match task	
Congruency	Conflict	Non-conflict	Conflict	Non-conflict
Incongruent trials				
1st post-WS-trial	10.0	3.1	5.6	2.5
2nd post-WS-trial	3.8	2.5	5.0	3.1
Costs	6.2	0.6	0.6	-0.6
Congruent post-Cue2-trial				
1st post-WS-trial	10.0	3.1	8.8	5.6
2nd post-WS-trial	6.9	0.6	6.3	6.9
Costs	3.1	2.5	2.5	-1.3
Congruent pre-WS-trial				
1st post-WS-trial	14.4	2.5	6.9	3.1
2nd post-WS-trial	7.5	2.5	3.1	3.1
Costs	6.9	0.0	3.8	0.0
Congruent post-WS-trial				
1st post-WS-trial	1.3	1.3	3.1	3.1
2nd post-WS-trial	8.8	1.3	8.8	3.8
Costs	-7.5	0.0	-5.7	-0.7

Note. The difference between the first and the second post-WS-trial gives the switch costs (%) on conflict blocks, and the restart costs (%) on non-conflict blocks.

CHAPTER 6

Summary and conclusions

This study investigated the ability to prepare for a switch to a new task while still doing an old task. The main question addressed in all experiments concerned the control mechanisms underlying the preparation for and the execution of a task switch in a situation with goals overlapping in time. Chapters 3, 4, and 5 focused, in addition, on more specific questions. Chapter 3 was dealing with self-paced preparation for a task switch. Chapter 4 addressed the question about the role of the interval between the implementation and the execution of a new task (i.e. number of trials intervening between Cue2 and WS) for the actual execution of a task switch. Finally, Chapter 5 investigated whether and how the combination of goal-directed control and stimulus-driven processing can promote an effortless task switch.

In this final chapter, we discuss what answers the present thesis provides by summarizing the main outcomes. First, we will focus on a comparison of the experimental conditions which are shared by the experiments reported in Chapters 2, 4, and 5. This concerns the conditions with two trials intervening between Cue2 and WS in which the post-Cue2-trial is either congruent or incongruent. This across-experiment comparison should provide us with a picture of the preparation for and the execution of a task switch, and more specifically, should inform us which aspects of the preparation and execution of a task switch prove to be stable and consistent across different experiments. This will be followed by a discussion of the more specific manipulations that were introduced in Chapters 3, 4, and 5.

Preparation for and execution of a task switch

In the task switching literature, there is an old debate over the control mechanisms underlying a task switch (e.g., see Allport et al., 1994; Gopher et al., 2000; Logan, 2003, 2004, Logan & Bundesen, 2003, 2004; Meiran, 1996; Meiran et al., 2000; Monsell, 2003; Rogers & Monsell, 1995; Rubinstein et al., 2001). However, there is a disagreement on what these control mechanisms are.

The present thesis is dealing with this issue, and more specifically with the control mechanisms underlying the preparation for and the execution of a task switch. In the following, we focus on these two aspects of a task switch. We therefore discuss the results about performance at: (1) the moment of implementation of a new task (i.e. at Cue2) while still doing an old task, i.e. transition costs (performance difference between conflict and non-conflict blocks on the post-Cue2-trial); and (2) the moment of actual execution of a task switch, i.e. switch costs (performance difference between the first and the second post-WS-trial).

As indicated above, the experiments reported in Chapters 2, 4, and 5 share conditions that are completely identical across the different experiments, but are embedded in varying other conditions in the three chapters. The shared conditions concern conflict and non-conflict blocks with two trials intervening between Cue2 and WS, with the post-Cue2-trial being either incongruent or congruent. These conditions occur in all experiments of Chapters 2, 4, and 5, always once with a CPT of 200 ms and once with a CPT of 900 ms. The comparison of these conditions will allow us to see which aspects of the patterns of results turn out to be stable across the other experimental manipulations that are introduced in the other experimental conditions of the respective experiments.

Let us start with CPT 200 ms. Figure 6.1 shows the transition costs (TCs) for the preparation of a task switch from color to form and from form to color for an incongruent and a congruent post-Cue2-trial, and the corresponding switch costs (SCs).

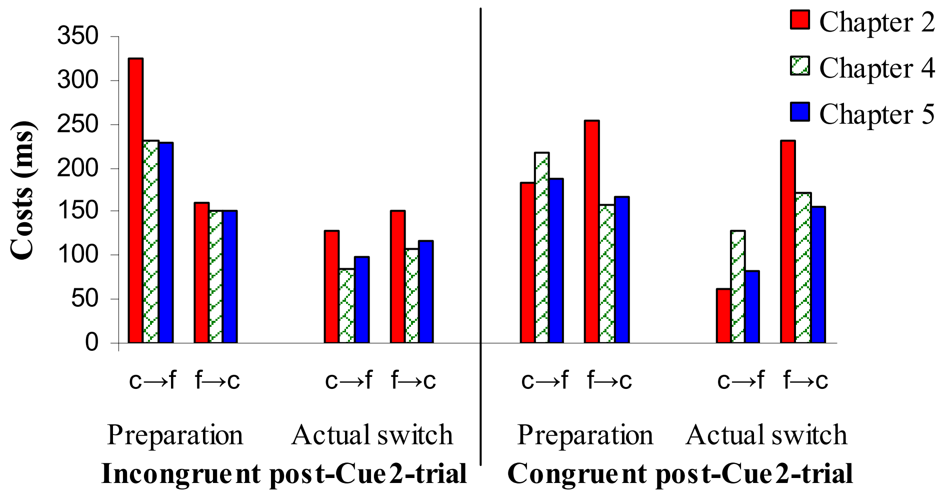

Figure 6.1. Transition costs and switch costs for Cue Presentation Time 200 ms as a function of the type of transition (color→form or form→color), Stimulus congruency on the post-Cue2-trial (incongruent or congruent), and Chapter (2, 4, or 5).

For an incongruent post-Cue2-trial, we see a descriptively consistent picture. *Preparing* a switch from color to form (while still *doing* the color task) incurs higher transition costs than preparing the switch from form to color. A corresponding ANOVA with the factors Chapter (2, 4, 5), Block type (conflict vs. non-conflict), and Actual task performed (color or form) confirms this descriptive pattern (significant interaction Block type by Actual task performed, $F(1, 2) = 27.5$, $p < .0001$; non-significant interaction between Block type, Actual task performed, and Chapter, $p > .1$).

The corresponding switch costs show descriptively a reversed asymmetry which, again, is consistent across the three experiments: The actual switch from color to form incurs less switch costs than the reverse task switch. However, the ANOVA with the factors Chapter (2, 4, 5), Order of execution (first post-WS-trial vs. second post-WS-trial), and Actual task performed (color or form) did not show a significant interaction between Order of execution and Actual task performed, $p > .4$ (the triple interaction between Order of execution, Actual task performed, and Chapter was also not significant, $p > .9$).

Note that the asymmetry in transition costs goes in the opposite direction of the asymmetry in switch costs. This result was substantiated statistically by an additional ANOVA with the factors Direction of the transition (color → form or form → color), Costs (transition vs. switch), and Chapter (2, 4, 5). The interaction Direction of the transition by Costs was significant ($F(1, 2) = 13.1$, $p < .001$), and this effect appeared irrespective of the factor Chapter (non-significant triple interaction between Direction of the transition, Costs, and Chapter, $p > .4$).

Thus, it appears that the time lost at the moment of implementation of a new task becomes a time gain at the moment of the actual execution of this task. More important in the present context, it seems that both, consciously initiated task-set reconfiguration as suggested by Monsell (e.g., Monsell, 2003, but see also Monsell et al., 2000; Rogers & Monsell, 1995) and task-set inertia as suggested by Allport (e.g., Allport et al., 1994; Wylie & Allport, 2000) take place in task switching. While the former process takes place at the preparation for a task switch the latter plays a role at the actual execution of a task switch.

For congruent post-Cue2-trials, the resulting picture with respect to transition costs is clearly less consistent. While Chapter 2 shows less transition costs for color to form, Chapters 4 and 5 show the reverse pattern. However, in a corresponding ANOVA with the factors Chapter (2, 4, 5), Block type (conflict vs. non-conflict), and Actual task performed (color or form), neither the interaction Block type by Actual task performed ($p > .9$) nor the triple interaction reached significance ($p > .1$).

By contrast, the switch costs again show a clear and consistent picture: SCs for color to form are smaller than SCs for the reverse direction, and this holds for Chapters

2, 4, and 5. The corresponding analysis revealed a reliable interaction between Order of execution and Actual task performed, $F(1, 2) = 13.2$, $p < .001$. The triple interaction between Order of execution, Actual task performed, and Chapter was not significant $p > .1$.

In summary, for CPT 200 ms, the data pattern appears to be fairly consistent except for the transition costs in case of congruent post-Cue2-trials. For incongruent post-Cue2-trials, we see an asymmetry in transition costs with higher costs for the transition from color to form than for the reverse direction. By contrast, for the moment of the actual task switch, switch costs were (at least descriptively, but consistent across experiments) in the opposite direction of the transition costs (i.e. higher switch costs for the transition from form to color than in the opposite direction). These results lead to the following conclusion: (1) If Cue2 would only be picked up as an indicator that one has to implement a new task at the warning signal, we would not expect the observed asymmetry in transition costs for short externally paced CPT. The asymmetry in transition costs fits well with the assumption of a consciously initiated task-set reconfiguration (endogenous, goal-directed control) as suggested by Monsell and colleagues (e.g., Monsell, 2003; Monsell et al., 2000; Rogers & Monsell, 1995). (2) If at WS the now relevant task was completely loaded (and thus the previous task was disengaged), we would not expect the observed asymmetry in switch costs. The asymmetry in switch costs is in line with Allport’s finding (e.g., Allport et al., 1994; Wylie & Allport, 2000) that the active disengagement from the previous task (task-set inertia) should be more difficult for the difficult task than for the easy task if the new task has not been fully implemented.

But why did the “preparation asymmetry” only obtain systematically for incongruent post-Cue2-trials? A possible explanation could be that an incongruent post-

Cue2-trial clearly marks the difference between the present task and the task to-be-prepared, and therefore only in this case a full preparation is carried out. Although this hypothesis is obviously speculative, it should be taken into account for further investigation of control processes in task switching.

The results show a different picture for CPT of 900 ms. The transition costs for the preparation of a task switch from color to form and from form to color for an incongruent and a congruent post-Cue2-trial, and the corresponding switch costs, are given in Figure 6.2.

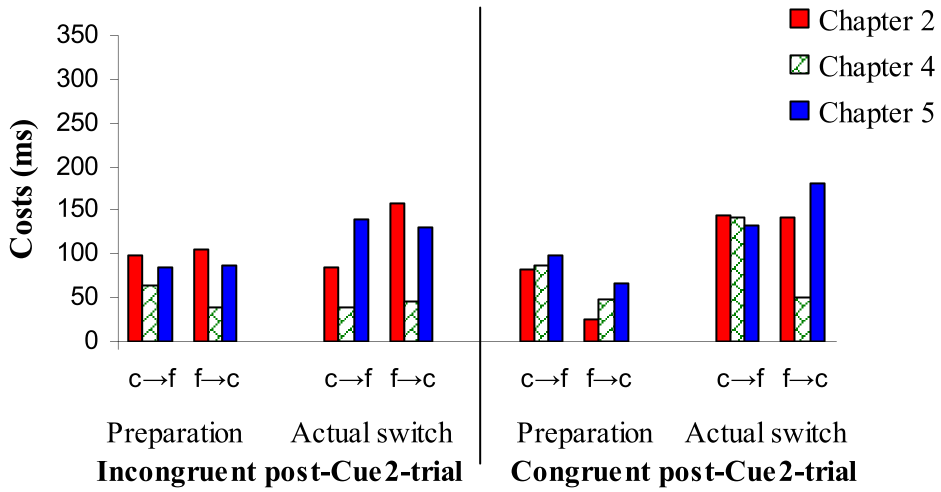

Figure 6.2. Transition costs and switch costs for Cue Presentation Time 900 ms as a function of the type of transition (color→form or form→color), Stimulus congruency on the post-Cue2-trial (incongruent or congruent), and Chapter (2, 4, or 5).

For CPT of 900 ms, four separate analyses were carried out using the same analytical procedure as for CPT of 200 ms. Although between chapters, descriptively, there were some differences in transition costs as a function of the direction of the transition, this result was not substantiated statistically. For the post-Cue2-trial, the ANOVAs with the factors Block type (conflict vs. non-conflict), Actual task performed (color or form), and Chapter (2, 4, 5) showed no reliable interaction between Block type and Actual task performed ($p > .7$ for incongruent post-Cue2-trial; and $p > .05$ for congruent post-Cue2-trial). Also the triple interaction Block type, Actual task performed, and Chapter was not reliable (*p* > .7 for incongruent post-Cue2-trial; and *p* > .8 for congruent post-Cue2-trial).

For the first and the second post-WS-trial (i.e. switch costs), the corresponding ANOVAs showed no significant interaction between Order of execution and Actual task performed (*p* > .3 when the post-Cue2-trial was incongruent; and *p* > .5 when the post-Cue2-trial was congruent). The interaction of Order of execution, Actual task performed, and Chapter was not reliable (*p* > .3 when the post-Cue2-trial was incongruent; and *p* > .05 when the post-Cue2-trial was congruent). Thus, it seems that with long CPT the asymmetry in switch cost that was observed for short CPT disappeared, presumably due to completed goal loading.

Next, we discuss whether and how the interval between Cue2 and WS (i.e. the implementation and the actual execution of a new task) influences the actual task switch.

The role of the interval between the implementation and the execution of a new task for the actual task switch

In Chapter 3, we asked whether participants could anticipate a task switch when they settle the speed for preparing and executing a task switch by their own rhythm (i.e. Cue1, Cue2, and WS being self-paced). The results show transition costs despite the fact that participants determined themselves how much time they spend on Cue2. Although on Cue2 the self-paced times (on average 1303 ms) were longer than 900 ms (i.e. long externally paced CPT), on the post-Cue2-trial, results for self-paced CPT are more in line with those for short externally paced CPT (see Experiment 1 of Chapter 2) than with those for long externally paced CPT (see Experiment 2 of Chapter 2). Thus, it appears that a long externally paced interval is used more effectively to prepare a task switch than a completely self-paced interval.

When we turn to the actual task switch, switch costs were reduced in comparison to the switch costs when participants were under time pressure (i.e. Cue1, Cue2, and the warning signal being externally-paced). However, there was no complete elimination of switch costs even when we provided participants with a completely self-paced interval between Cue2 and WS. This suggests that the completely self-paced mode is not sufficient to eliminate switch costs. This finding is in line with some previous findings that residual switch costs could not be eliminated even with prolonged preparation times (e.g., Allport et al., 1994; De Jong, 2000; Meiran, 1996, 2000a; 2000b; Meiran et al., 2000; Meiran & Gotler, 2001; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995).

In Chapter 4, we asked how the number of trials intervening between Cue2 and WS influences the preparation for and the execution of a task switch. Therefore, the main manipulation concerned a variation of the number of trials intervening between Cue2 and WS, i.e. one, two, three, or four trials. In addition, the Cue Presentation Time was manipulated between participants, i.e. short externally paced interval (i.e. 200 ms) vs. long externally paced interval (i.e. 900 ms).

In the following we focus on whether and how the interval between Cue2 and WS (i.e. CWI) is used for a better preparation of an upcoming task switch. The potential effect of this preparation can be seen at the actual execution of a task switch (i.e. right after WS).

For the actual execution of a task switch, two alternative hypotheses were tested: (1) If the interval between Cue2 and WS is used for establishing the new task while still performing the old task, a monotonic decrease of the switch costs would be expected with longer CWI. (2) If the interval between Cue2 and WS is used for solving the conflict between the two competing tasks, and therefore for suppressing the second task, a monotonic increase of switch costs would be expected. The results about switch costs did not support any of these scenarios (see Figure 4.1 in Chapter 4).

When the actual task performed was the relatively difficult (form match) task, switch costs did not differ with respect to the number of trials intervening between Cue2 and WS (CWI), and this holds for both, short and long externally paced CPT. When the actual task performed was the relatively easy (color match) task, switch costs were highest when there was only one trial between Cue2 and WS. This result was substantiated statistically only for a long CPT of 900 ms. A closer look at the results showed that for long CPT, there was no further reduction of switch costs with a prolongation of CWI to more than two trials. Therefore, it appears that providing participants with more trials between Cue2 and WS (i.e. long CWI) does not lead to a systematic reduction of switch costs.

Elimination of switch costs

In Chapter 5 we asked whether and how the combination of goal-directed control and stimulus-driven processing can promote an effortless switch.

In this study the CWI was fixed on two trials, i.e. WS appeared two trials after Cue2 (this distance between Cue2 and WS was chosen based on the results from Chapter 4; recall that a prolongation of CWI to more than two trials did not lead to a further reduction in switch costs). The main manipulation in Chapter 5 concerned the trial position at which a congruent stimulus was presented. Either the post-Cue2-trial was congruent or incongruent, or the second trial after Cue2, or the post-WS-trial. In this respect, the present experiments differ from other studies, in which stimulus in-

/congruency was manipulated primarily at the switch trial (e.g., see Goschke, 2000; Hunt & Klein, 2002; Kleinsorge & Gajewski, 2006; Koch & Allport, 2006; Meiran, 2000b; Rogers & Monsell, 1995; Ruthruff et al., 2001; Wylie & Allport, 2000; Yeung & Monsell, 2003).

When the switch trial (i.e. the post-WS-trial) was incongruent, there were switch costs. These switch costs appeared irrespective of stimulus congruency of the trials intervening between Cue2 and WS.

By contrast, when the switch trial itself was congruent, switch costs were eliminated, or even turned into a switch gain; switch costs were reduced for the switch from form to color, and switch costs turned into a switch benefit for the switch from color to form. These results show that an appropriate combination of goal-directed and stimulus-driven influences can lead to an effortless task switch.

To conclude, the results from the present thesis show that two control mechanisms, goal-directed control and stimulus-driven processing guide the preparation for and the execution of a task switch. While goal-directed control is primarily involved in the preparation for a task switch, stimulus-driven processing takes place at the actual execution of a task switch. Furthermore, under certain circumstances these two mechanisms can promote an effortless task switch.

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Samenvatting

In het dagelijks leven is het vaak vereist dat meerdere taken tegelijkertijd of snel achter elkaar worden uitgevoerd, bijvoorbeeld wanneer mensen een auto besturen terwijl ze mobiel aan het bellen zijn of wanneer mensen water drinken wanneer ze een presentatie geven. Er is veel wetenschappelijke literatuur verschenen die probeert te verklaren hoe het wisselen (“switchen”) tussen taken wordt bereikt. Gewoonlijk gaat switching tussen taken gepaard met tijdgerelateerde kosten en fouten, die bekend staan als switchkosten. Deze kosten worden gezien als een reflectie van de controlemechanismen die ten grondslag liggen aan de voorbereiding en uitvoering van een taakswitch.

Uit eerdere studies kwamen twee belangrijke standpunten over controleprocessen in taakswitching naar voren. Enerzijds schreef Monsell (e.g., Monsell, 2003; Rogers & Monsell, 1995) switchkosten toe aan bewust geïnitieerde taakset reconfiguratie (endogeen, top-down controle). Deze taakset configuratie wordt later voltooid door stimulusgedreven verwerking (exogeen, bottom-up controle). Anderzijds veronderstelden Allport en collegae (e.g., Allport, Styles, & Hsieh, 1994; Wylie & Allport, 2000) dat switchkosten niet gezien mogen worden als het resultaat van executieve controleoperaties, maar als een index van poststimulus interferentie van een net aangenomen taakset. Ze hebben dit effect taakset inertie (TSI) genoemd.

Dit proefschrift behandelt het onderwerp van controlemechanismen in taakswitching. Wij stellen een nieuw paradigma voor, het “Overlapping Cues Paradigma” (OCP) als een experimenteel instrument om de controlemechanismen te onderzoeken die ten grondslag liggen aan de voorbereiding en uitvoering van een taakswitch. Deze benadering biedt de mogelijkheid om apart te kijken naar a) de voorbereiding van een nieuwe taak tijdens het uitvoeren van een oude taak en b) de daadwerkelijke switch van de oude taak naar de nieuwe taak. Met andere woorden, we onderscheiden twee aspecten van taakswitching die in de klassieke taakswitching paradigma’s (e.g., Allport et al., 1994; Jersild, 1927; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995; Spector & Biederman, 1976; Sudevan & Taylor, 1987) plaatsvinden binnen een en dezelfde trial, de switchtrial.

In het Overlapping Cues Paradigma (zie Figuur 1.1, pagina 5 van dit proefschrift) worden, binnen een blok van 16 trials, twee cues aangeboden, die aangeven welk van de twee taken uitgevoerd moet worden (in onze experimenten, ofwel een kleur ofwel een vorm “match” taak). Cue1 wordt aangeboden aan het begin van een blok en Cue2 na trial 8. Verscheidene trials na Cue2 wordt een ster-symbool aangeboden als een waarschuwingssignaal (WS). De twee cues zijn ofwel gelijk (Cue1 = Cue2, de zogenaamde cue non-conflict conditie) ofwel verschillend (Cue1 ≠ Cue2, de zogenaamde cue conflict conditie). Proefpersonen werden geïnstrueerd om tot het WS de taak uit te voeren die door Cue1 werd aangegeven en daarna de taak uit te voeren die werd aangegeven door Cue2. Op deze manier vereist het WS een taakswitch binnen cue conflict blokken maar niet binnen cue non-conflict blokken.

Logischerwijs, is in OCP het belangrijkste deel van het blok het interval tussen Cue2 en WS (Cue2 waarschuwingsignaal interval, CWI) en de twee trials na WS. De belangrijkste focus in dit proefschrift betreft manipulaties binnen dit kritische deel van een blok. Alle in dit proefschrift beschreven experimenten onderzoeken de controlemechanismen die ten grondslag liggen aan de voorbereiding en uitvoering van een taakswitch in een situatie waar doelen overlappen in de tijd. Hoofdstuk 2 behandelt de manier waarop stimulusgedreven en doelgerichte aspecten van controle in taakswitching kunnen worden onderscheiden. Hoofdstuk 3, 4 en 5 spitsen zich vervolgens toe op meer specifieke vragen. Hoofdstuk 3 gaat over zelfgeïnduceerde voorbereiding van een taakswitch. Hoofdstuk 4 houdt zich bezig met de vraag wat de rol is van het interval tussen de implementatie en de uitvoering van een nieuwe taak (i.e. het aantal trials tussen Cue2 en WS) voor de daadwerkelijke uitvoering van een taakswitch. Ten slotte wordt in Hoofdstuk 5 onderzocht of, en zo ja hoe, de combinatie van doelgerichte controle en stimulusgedreven verwerking een moeiteloze taakswitch kan bewerkstelligen.

De resultaten van de huidige studie wijzen er sterk op dat:

1) Zowel een bewust geïnitieerde taakset configuratie, voorgesteld door Monsell en collegae (e.g., Monsell, 2003; Rogers & Monsell, 1995), als een actieve loskoppeling van de vorige taak (taakset inertie), voorgesteld door Allport en collegae (e.g., Allport et al., 1994; Wylie & Allport, 2000) spelen een rol bij taakswitching. Het eerste proces lijkt voornamelijk een rol te spelen bij de *voorbereiding* van een taakswitch (laden van een nieuw doel op basis van Cue2), terwijl het tweede proces voornamelijk een rol lijkt te spelen bij de daadwerkelijke *uitvoering* van de taakswitch.

2) Wanneer proefpersonen de mogelijkheid krijgen om de snelheid van uitvoeren aan te passen aan hun eigen ritme (i.e. Cue Presentatie Tijd is zelfbepaald) kan dit leiden tot een betere voorbereiding op een naderende switch. Deze zelfbepaalde wijze is echter niet voldoende om switchkosten te elimineren.

3) Wanneer proefpersonen meer trials tussen Cue2 en WS (i.e. lange CWI) krijgen aangeboden, leidt dit niet tot systematische reductie van switchkosten. Deze bevindingen komen overeen met enkele eerdere bevindingen dat zogenoemde residuele switchkosten zelfs niet kunnen worden geëlimineerd met verlengde voorbereidingstijden (e.g., Allport et al., 1994; De Jong, 2000; Meiran, 1996, 2000a; 2000b; Meiran et al., 2000; Meiran & Gotler, 2001; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995).

4) Wanneer de switchtrial, i.e. de post-WS-trial, incongruent is (i.e. de twee taken vereisen verschillende responsen, linker plaatje in Figuur 1.2, pagina 7 van dit proefschrift) treden er switchkosten op. Deze switchkosten lijken onafhankelijk te zijn van stimuluscongruentie van de trials tussen Cue2 en WS. Aan de andere kant, wanneer de switchtrial zelf congruent is (i.e. de taken vereisen dezelfde response, rechter plaatje in Figuur 1.2, pagina 7 van dit proefschrift) worden de switchkosten geëlimineerd of gaan ze zelfs over in een switchvoordeel; switchkosten zijn gereduceerd voor de switch van vorm naar kleur, en switchkosten veranderen in een switchvoordeel voor de switch van kleur naar vorm. Deze resultaten laten zien dat een geschikte combinatie van doelgerichte controle en stimulusgedreven invloeden kan leiden tot een moeiteloze taakswitch.

Concluderend, de resultaten van het huidige proefschrift laten zien dat twee controlemechanismen, doelgerichte controle en stimulusgedreven verwerking, de voorbereiding en uitvoering van een taakswitch sturen. Waar doelgerichte controle voornamelijk betrokken is bij de voorbereiding van een taakswitch, vindt stimulusgedreven verwerking plaats bij de daadwerkelijke uitvoering van een taakswitch. Daarnaast, kunnen deze twee mechanismen onder bepaalde omstandigheden een moeiteloze taakswitch bewerkstelligen.

Резюме

В ежедневието често извършваме различни задачи едновременно или в бърза последователност, като например говорене по мобилен телефон по време на шофиране или пиене на вода по време на презентация. Какви са механизмите на тези процеси? Как постигаме превключване между задачи? Това са част от въпросите, на които научната литература по превключване между задачи се опитва да даде обяснение. Обикновено превключването между задачи е съпроводено с времеви разходи и грешки, познати като разходи при превключване. Предполага се, че тези разходи са резултат от контролни механизми стоящи в основата на подготовката и осъществяването на превключване между задачи.

В специализираната литература се очертават две противоположни позиции обясняващи контролните механизми при превключване между задачи. От една страна, Монсел и колеги (Монсел, 2003; Роджерс и Монсел, 1995) смятат, че разходите при превключване между задачи са резултат от съзнателно инициирано реконфигуриране на задачи, т.нар. ендогенен, цел-детерминиран („top-down”) контрол. Това реконфигуриране завършва (по-късно) с участието на стимул-детерминиран процес, т.нар. екзогенен („bottom-up”) контрол. Обратно, според Алпорт и колеги (Алпорт, Стайлс и Хсиех, 1994; Уили и Алпорт, 2000) разходите при превключване не бива да бъдат считани за резултат от изпълнителни контролни операции, а трябва да се разглеждат като резултат от пост-стимулно взаимодействие при прехода към нова задача. Те наричат този ефект инерция при реконфигурация на задачи.

За да се хвърли светлина върху този дебат са необходими нови изследвания. Настоящата дисертация фокусира върху този проблем: изследва контролните механизми при превключване между задачи.

Ние предлагаме нов подход: Парадигмата на Препокриващи се Опори (ППО), като средство за изследване на контролните механизми стоящи в основата на подготовката и извършването на превключване между задачи. Този подход дава възможност да разглеждаме по отделно (а) подготовката за изпълнение на нова задача по време на изпълнението на стара задача, и (б) актуалното изпълнение на превключването от старата към новата задача. С този подход ние разграничаваме два аспекта на превключването между задачи, които в класическите парадигми за превключване между задачи (Алпорт и др., 1994; Джерсилд, 1927; Мейран, 1996; Мейран, Корев и Сапир, 2000; Роджерс и Монсел, 1995; Спектор и Биедерман, 1976; Судеван и Тайлор, 1987) се осъществяват в един и същ момент, момента на изпълнение на превключването между задачи.

В Парадигмата на Препокриващи се Опори (виж Фигура 1.1, страница 5), две опори са представени в блок от 16 проби (всяка проба се състои от стимул и отговор). Тези опори определят каква задача трябва да се изпълнява (в нашия експериментален случай, задачите са за намиране на съвпадение по цвят или по форма). Опора1 е представена в началото на блока, а Опора2 след Проба8. Няколко проби след Опора2 се представя визуален предупредителен сигнал (в случая, звезда). Двете опори са или различни (Опора1 # Опора2, т.нар. условие на конфликт между опори), или еднакви (Опора1 = Опора2, т.нар. условие без конфликт между опори). Участниците са инструктирани да изпълняват задачата индикирана от Опора1 до появата на визуалния предупредителен сигнал, а след него да изпълняват задачата индикирана от Опора2. По този начин визуалният предупредителен сигнал определя изпълнението на превключване между задачи при условие на конфликт между опори, но не и когато опорите са еднакви.

Очевидно е, че при Парадигмата на Препокриващи се Опори най-важната част от експерименталния блок е интервалът между Опора2 и предупредителния сигнал, както и двете проби след предупредителния сигнал.

Основната линия на изследване в настоящата дисертация включва манипулации на този критичен интервал от експерименталния блок.

Всички експерименти изследват контролните механизми стоящи в основата на подготовката и изпълнението на превключване между задачи, в ситуация на препокриващи се във времето цели. Втора глава се занимава с разграничаване на стимул-детерминиран от цел-детерминиран аспекти на контрола при превключване между задачи. Трета, четвърта и пета глави фокусират допълнително върху по-специфични въпроси. Трета глава изучава подготовката за превключване между задачи при условие на пълен контрол върху времето на реакция от страна на изследваните лица (т.е. Опора1, Опора2, и предупредителният сигнал са представени на екрана на компютъра до момента, в който изследваното лице натисне клавиш, за да продължи със следваща проба). Четвърта глава разглежда въпроса за ролята на интервала между въвеждането и изпълнението на нова задача (т.е. броя на проби между Опора2 и предупредителния сигнал) за актуалното изпълнение на превключването между задачи. Пета глава изследва дали и как комбинацията от цел-детерминиран контрол и стимул-детерминиран процес може да елиминира разходите при превключване между задачи.

Резултатите от настоящата научна разработка показват:

(1) Двата механизма: съзнателно инициирана реконфигурация на задачи предложена от Монсел и колеги (Монсел, 2003; Роджерс и Монсел, 1995), както и инерция при реконфигурацията на задачи предложена от Алпорт и колеги (Алпорт и др., 1994; Уили и Алпорт, 2000) играят роля за превключване между задачи. Докато първият процес взима активно участие при *подготовката* за превключване между задачи (напр. зареждане на нова цел въз основа на Опора2), то вторият процес играе роля при актуалното *изпълнение* на превключването между задачи.

(2) Възможността изследваните лица сами да определят времето за реакция и, следователно, скоростта за изпълнение на дадена задача води до по-добра подготовка за предстоящото превключване между задачи. Въпреки това, самостоятелното определяне на времето за реакция от страна на изследваните лица не е достатъчен фактор за елиминиране на разходите при превключване между задачи.

(3) Увеличаването на броя на пробите между Опора2 и предупредителния сигнал не води до систематично намаляване на разходите при превключване. Тези открития са в унисон с някои предишни открития, че т.нар. остатъчни разходи при превключване между задачи не могат да бъдат елиминирани дори с увеличаване на времето за подготовка за превключване между задачи (Алпорт и др., 1994; Дьо Йонг, 2000; Мейран, 1996, 2000а, 2000б; Мейран и др., 2000; Мейран и Готлер, 2001; Монсел, Йънг и Азума, 2000; Роджерс и Монсел, 1995).

(4) Когато пробата, при която се осъществява актуалното изпълнение на превключването между задачи се състои от инконгруентен стимул (т.е. двете задачи изискват различен отговор, виж ляв панел на Фигура 1.2, страница 7), се

наблюдават разходи при превключване между задачи. Тези разходи не зависят от конгруентността на стимулите представени между Опора2 и предупредителния сигнал. Обратно, когато пробата, при която се осъществява актуалното изпълнение на превключването между задачи се състои от конгруентен стимул (т.е. двете задачи изискват един и същ отговор, виж десен панел на Фигура 1.2, страница 7), разходите при превключване са елиминирани (при прехода от задача „Форма" към задача „Цвят") или дори се превръщат в печалба (при прехода от задача „Цвят" към задача „Форма"). Тези резултати показват, че подходяща комбинация от цел-детерминиран контрол и стимул-детерминиран процес може да елиминира разходите при превключване между задачи.

В заключение, резултатите от настоящата дисертация показват, че двата контролни механизма, цел-детерминиран контрол и стимул-детерминиран процес управляват подготовката и изпълнението на превключване между задачи. Докато цел-детерминирания контрол взима участие основно в подготовката за превключване между задачи, то стимул-детерминирания процес играе роля при актуалното изпълнение на превключването между задачи. Нещо повече, при определени обстоятелства тези два механизма могат да доведат до елиминиране на разходите при превключване между задачи.

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на извор от любов що ти създаваш
и със слънце моя ден огряваш,
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CURRICULUM VITAE

Svetlana Bialkova was born on 12th July 1974 in Malko Tarnovo, Bulgaria. There she has got her secondary school diploma (1992). Svetlana started her university studies in 1992, studying Chemistry and Physics at the Sofia University "St. Kliment Ohridski", Bulgaria. She obtained a Higher education diploma (1997), an MSc in Chemistry and Physics, and a "Qualification Teacher of Chemistry and Physics". For few years she was teaching chemistry and physics at secondary school. In September 2000, Svetlana started to study Cognitive Science at the New Bulgarian University, Sofia, Bulgaria. In July 2003, Svetlana was admitted to the PhD programme in Cognitive Science at the Nijmegen Institute for Cognition and Information (NICI), The Netherlands. Since September 2006 Svetlana has been working as a postdoctoral researcher at the Department of Experimental Psychology, University of Bristol, UK.