Investigations on the Shielding Function of Task Sets and its Underlying Mechanism

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Preface

Whenever we act in accordance with current goals – induced endogenously by intentions or exogenously through instructions – cognitive control allows us to focus on the task at hand, overcome habits, or apply newly learned rules and associations. At the same time, it enables us to flexibly shift between goals and modify actions when the need for switching arises. In cognitive psychology this ability to shift is mostly studied using the task switching paradigm, where subjects are instructed to switch between two or more simple tasks. Their performance is usually slower and more error-prone on a switch of task than on a repetition. This *switch cost* is sometimes believed to reflect an endogenous control process (Rogers & Monsell, 1995), while others attribute it to persisting activation of the preceding task and/or lingering inhibition of the current task (e.g. Allport, Styles, & Hsieh, 1994). In any case, switching between tasks is associated with a robust cost. In 2007, Dreisbach, Goschke, and Haider were able to show that this cost disappears if subjects respond based on a number of stimulus-response mappings (SR mappings) rather than two alternating rules. That is, with an alternative strategy the switch cost can be avoided. Still, even when the use of separate mappings was implicitly suggested by introducing targets two at a time, subjects opted for rule use. Thus, the question arose why the use of task rules seems to be preferred over SR mappings (as indicated by the existence of switch costs), despite being associated with a cost. In 2008, Dreisbach and Haider found an appealing answer to this question: When the use of separate SR mappings was compared to applying a *single* rule instead of two rules, a benefit of rule application emerged. The use of rules prevented interference by irrelevant stimulus features. More precisely, Dreisbach and Haider looked into binding effects between an irrelevant target feature (stimulus color) and the response. Typically, response repetitions are faster when they are accompanied by a feature repetition, whereas a feature switch benefits a response switch (e.g. Notebaert & Soetens, 2003). Dreisbach and Haider found this effect only when subjects applied eight separate SR mappings instead of a single categorization rule. They termed the fact that task rules prevented such binding effects the *shielding function of task sets*. In 2009 they extended their findings by showing that the shielding function does not only affect binding effects but also prevents interference from spatially oriented distracters. In sum, using task rules may result in costs when the need to switch arises. But it also offers the advantage of shielding from irrelevant information.

With the presence of the shielding function being established, questions regarding its underlying processes must be addressed. The absence of interference due to the use of categorization rules might be achieved by the suppression of distracters, by a preference for information related to the task, or by a combination of both factors. In the experiments presented here, shielding was investigated in the presence of task-related distracters. Moreover, results indicating a relaxation of shielding on task switches (Dreisbach & Wenke, 2011) were utilized while studying shielding in the context of predictable and unpredictable task switching. The aim of the present thesis was to shed more light on the shielding function of task sets and its underlying mechanism. It was hypothesized that the shielding function reflects a preference for task-related information.

CONTENTS

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ABSTRACT

The flexibility of the human mind is often studied using the task switching paradigm. Subjects are instructed to alternate between two or more tasks and typically perform worse on a task switch than on a repetition. Dreisbach and colleagues (Dreisbach et al., 2007; Dreisbach & Haider, 2008, 2009) investigated whether rule use is only associated with this detrimental effect – the cost of switching – or also offers benefits. They found that applying categorization rules instead of seemingly arbitrary stimulus-response mappings results in reduced susceptibility to distraction and termed this effect the *shielding function of task sets*. The present thesis addressed open questions regarding this shielding function. I investigated how shielding affects task-related distraction as compared to the irrelevant distracters Dreisbach and Haider had used. In addition, shielding was studied in the context of unpredictable and predictable task switching in order to further investigate its underlying mechanism. Results show that using task rules enables subjects to avoid distraction by focusing on task-related information. This was deduced from the facts that a) stimuli that fit the instructed categories were automatically categorized and b) a reduction of shielding did not result in an overall increased distractibility but led to attenuated interference by task-related distracters. Overall, shielding seems to be possible because – in contrast to arbitrary SR mappings – rules offer a single and common response-defining stimulus feature. The observed preference for such task-related information is modulated by task activation, as evidenced by a reduction of shielding on unpredictable but not on predictable task switches.

PART I

THEORETICAL BACKGROUND

COGNITIVE CONTROL

AN INTRODUCTION TO COGNITIVE CONTROL

Imagine a sunny Sunday afternoon. You are sitting in your back yard with some friends, drinking cold beverages, talking and playing a game of cards. Reaching for your glass and taking a sip or shuffling the deck of cards are both actions that are easily done and require no mental effort. Others appear just as trivial from the outside but may in fact be more demanding. For instance, you might put milk in your coffee and – because you are on a diet – refrain from adding sugar although you typically do. In order to win the game you must keep track of which cards have been played or which suit currently trumps. Moreover, you may play different games with different rules and have to adapt accordingly. All these actions seem trivial and yet they are subject to some form of control because they reflect your current goals or present circumstances. The study of what this *control* is and how it operates, has a long history in psychology (Ach, 1910; James, 1890). The psychological construct is addressed with terms such as *the will* (Ach, 1910; James, 1890) or *executive control* (e.g. A.-L. Cohen, Bayer, Jaudas, & Gollwitzer, 2008; Logan, 1985; Rubinstein, Meyer, & Evans, 2001) over *executive functions* (e.g. Alvarez & Emory, 2006; Davidson, Amso, Anderson, & Diamond, 2006; Hofmann, Schmeichel, & Baddeley, 2012; Phillips, Bull, Adams, & Fraser, 2002). The question asked is always the same: How do we manage to do the things we do the way we are instructed to do them or want to do them in the presence of distractions, temptations, or competing response tendencies? How can we pursue our goals in spite of, for instance, habits or currently more appealing alternatives? To illustrate the importance of control, authors often resort to reports of patients who seem to have lost some aspect of it. One of the most often cited examples is the very memorable *utilization behavior* (Lhermitte, 1983). Patients suffering from frontal lesions sometimes seem unable to inhibit habitual responses to everyday objects, even if they have no intention of using them. For instance, the presentation of a cigarette and a match would trigger using the match to light the cigarette, although the patient might not even be a smoker. It seems as though the objects evoke an automated response that cannot be controlled by the patient's will.

Cognitive control allows us to overcome such habitual tendencies and govern our behavior according to current intentions, goals, or circumstances. Complex cognitive tasks can only be mastered when the necessary processes are sequenced and coordinated. In cognitive psychology, this controlled processing is often contrasted with actions that can be carried out in a purely automatic fashion. This distinction suggests that there is a clear dichotomy between automatic and controlled behavior: On the one hand, there are automatic processes that are triggered by external stimuli and can be seen through fast and effortlessly, without consciousness or attention. For example, you could easily scratch your itching arm while reading these lines without having to interrupt your ongoing activity or think about how to move your fingers. On the other hand, there are actions that serve an intention and need to be directed in one way or the other. Stopping the scratching motion because you do not want the mosquito bite to turn into a scar would be an instance of such behavior. Yet, although the distinction between automatic and controlled processes might be appealing, Goschke (2003) notes that it does not do the complexity of behavior justice. He refers to instances, where newly learned (and therefore necessarily controlled) actions seem to be carried out in an automatic fashion, such as in priming studies. In contrast, even highly automatic behavior is not carried out whenever circumstances suggest it (a notable exception is the *utilization behavior* mentioned above). It partly depends on current goals and sometimes must be initiated deliberately. Although you might be excellent at shuffling cards, you would not shuffle any deck of cards you encounter. Only if you intended to play would you take the cards and (maybe automatically) shuffle the deck.

Overall, how behavior is controlled is a complex issue and only 16 years ago still was – as Monsell (1996) beautifully put it – "a somewhat embarrassing zone of almost total ignorance – a heart of darkness" (Monsell, 1996, p. 93). This has changed, especially in view of new techniques, such as functional magnetic resonance imaging. A lot has been done to uncover this *heart of darkness*, and some of the light that has been shed will be presented here.

The number of possible situations, where behavior is in need of adjustments, modifications, or some other form of cognitive control is infinite. Three main functions (Miyake et al., 2000) are illustrated by the examples in the very first paragraph of this chapter: inhibition of prepotent responses (not putting sugar in your coffee), monitoring and updating of information in working memory (keeping track of the cards), and shifting between mental sets (switching to another card game). Others include planning, problem solving, and novel situations where stimuli are associated with newly instructed or to-be-learned responses (Alvarez & Emory, 2006; Norman & Shallice, 1986). It is evident that the number of cognitive control functions is vast. So how exactly do they work? Is cognitive control a unitary agent, situated somewhere in the brain – a homunculus that always just *knows* how to act? Or is it a distributed network of functions, a non-unitary system that has multiple components for a variety of control demands?

COGNITIVE CONTROL AND THE PREFRONTAL CORTEX

It has been attempted repeatedly to answer this question. Influential models have been proposed to account for phenomena associated with cognitive control. In their model of working memory, for instance, Baddeley and Hitch (1974) postulated a *central executive* that coordinates two subordinate slave systems: the phonological loop and the visuo-spatial sketchpad (later a third system, the episodic buffer was added; Baddeley, 2000). The former controls flow of information to and from the latter, where verbal and visuo-spatial information, respectively, are stored for short-term use. In a similar vein but on a more general level, Norman and Shallice (1986) proposed the existence of a *supervisory attentional system* (SAS) that controls the activation and selection of more basic components called schemas. According to Norman and Shallice, automatic behavior is served by schemas that are activated by external triggers and – once they reach a specific threshold of activation – are selected and seen through unless they are actively switched off. Schemas can be rather basic (e.g. closing your fingers in order to grab a card) or more refined *source schemas* that activate a group of supporting schemas (e.g. the source schema *playing a card* would activate the correct hand- and finger-motions, aiming and grasping schemas etc.). In order to avoid conflict, the selection of schemas for simple and well-learned acts is supported by contention scheduling: lateral activation or inhibition of supporting and conflicting schemas, respectively, reduces competition. Importantly, according to this model, whenever external schema activation is not sufficient for the fulfillment of current goals, attention and motivation can influence behavior through the SAS, the central agent of control. They do so indirectly by increasing or decreasing schema activation values. That is, attention affects the selection of appropriate schemas but not their execution. Both Baddeley and Hitch's model and Norman and Shallice's model seem to favor a unitary approach: A central system or executive is responsible for administering control. This view is often mirrored in neuroimaging studies. The prefrontal cortex (PFC) is widely assumed to be the anatomical equivalent to a supervisory control system. Compelling evidence for the involvement of this structure in executive control first came from neuropsychological studies with patients suffering from lesions of the PFC. Such lesions usually lead to impairments in tests that commonly are assumed to tap executive functions. However, a recent review highlights the importance of distinguishing between specificity and sensitivity of such tasks to frontal lobe lesions (Alvarez & Emory, 2006). Alvarez and Emory put forward that their three tested tasks (the Wisconsin Card Sorting test, phonemic verbal fluency, and the Stroop Color Word Interference test) are sensitive to frontal lobe lesions because patients typically perform more poorly than healthy controls (although there are exceptions to this rule). However, they are not specific to lesions of the PFC because diffuse non-frontal lesions can lead to the same impairments. Still, even with doubts about its sufficiency for controlled behavior, the PFC is considered to be a necessary component of any goal-directed or intention-based behavior. Miller and Cohen (2001) argued that it has all the necessary prerequisites a superordinate control system might require. It is widely connected to other areas of the brain, efferently as well as afferently. Information converges and is integrated in the PFC. Miller and Cohen suggest that sustained activation of the PFC reflects the representation of current goals and biases brain structures that are necessary for the completion of these goals. Its purpose is “the active maintenance of patterns of activity that represent goals and the means to achieve them” (Miller & Cohen, 2001, p.171). Of course, in order to fulfill more basic task demands such as perceiving and processing the relevant stimuli or initiating motor responses other areas of the brain are necessarily involved. The PFC is presumable merely the source of modulating influences on more posterior regions. For instance, Egner and Hirsch (2005) found that following response conflict (in this case a target face superimposed with an incongruent distracter name), activity in the task-relevant regions (the face-selective fusiform face area, FFA) was increased. This amplification was accompanied by an increase in connectivity between the FFA and the dorsolateral PFC. Egner and Hirsch interpreted the findings in terms of the recruitment of control following conflict (dorsolateral PFC activation), which signals the need for increased activity in task-relevant areas (FFA activation). In a similar vein, it has been found that greater activity in the supposedly conflict-sensitive anterior cingulate cortex (ACC; Botvinick, Braver, Barch, Carter, & Cohen, 2001) was followed by increased activity in the PFC and behavioral adjustments in the subsequent trial (Kerns et al., 2004). In sum, various parts of the PFC may be recruited when the need for control arises. These, in turn, might bias the brain structures that are necessary for carrying out the tasks or pursuing the goals at hand (e.g. Brass, Ullsperger, Knoesche, Von Cramon, & Phillips, 2005).

THE REPRESENTATION OF TASK SETS

The purpose of cognitive control is to allow behavior to be governed by goals and intentions rather than environmental stimulation only. These goals and intentions may range from short term (play a card that trumps your opponent’s card) to long term (become an expert at the game), and from specific (win the game) to vague (socialize with people). As a consequence, one action might be attributed to a varying set of goals. Writing these sentences might serve my goal to finish at least three pages today. Alternatively (or additionally) writing could be construed to serve my wishes to finish this thesis, make the last three years’ work worthwhile, make my parents proud or promote my chances for getting a good job afterwards.

In cognitive psychology, the goals that are induced and studied in participants are – for reasons of convenience and clarity – often simple tasks. Subjects are instructed to act according to a specific rule or set of rules that might be new (e.g. press keys in response to certain targets) or rather familiar (e.g. naming objects), simple (e.g. always perform the same operation) or more complex (e.g. switch tasks depending on context or cues). The locus and nature of cognitive control is then inferred from measures such as reaction times, error rates, or neuroimaging results.

The notion that – once again – the PFC is vital to the representation of tasks and goals is emphasized in a review by Sakai (2008). Single-cell studies on monkeys as well as neuroimaging studies with human subjects show that activation of regions in the PFC is essential to task representation, maintenance, and execution. Depending on the sensory modality, the specific operation to be performed, or the abstractness of the task, different frontal regions might be relevant. For instance, Sakai suggests a rostro-caudal gradient concerning abstractness. That is, the more abstract the task is, the more frontal the corresponding activation within the PFC will be. This account is also elaborated on by Bunge and Zelazo (2006), who suggest that children's ability to use increasingly complex rules depends on developmental changes within the PFC. The orbitofrontal cortex, which the authors assume to represent simple associations between stimuli and corresponding rewards, is subject to structural changes very early in life. The ability to use more complex rules (e.g. rules that depend on context or may offer different responses for a single stimulus) increases between the ages of 2 and 5 years and may represent changes in the dorso- and ventrolateral PFC. Finally, the comparatively late development of the rostrolateral PFC allows the representation of higher-order rules like selection between multiple task sets. The ability to represent tasks abstractly seems to be especially important when it comes to generalization to new targets. Kharitonova, Chien, Colunga, and Munakata (2009) divided children into two groups, depending on their ability to switch rules. *Switchers* had no problem sorting cards by object first and by color afterwards. *Perseverators* stuck with the first rule they learned but performed that task equally well as switchers. Yet, when the same rule had to be used on new stimuli (e.g. cards had still to be sorted by color, but new colors were used), switchers had no difficulty generalizing, whereas perseverators – albeit using their preferred, first rule – performed poorly. Kharitonova et al. suggested that switchers and perseverators represented the rules differently. Switchers used *active* representations through sustained firing of neurons in the PFC, whereas perseverators' *latent* rule representations relied on changed neuronal connections in more posterior regions. Importantly, only the former seemed to allow generalization and switching between tasks.

THE STABILITY AND FLEXIBILITY OF BEHAVIOR

The ability to select between multiple tasks and switch if necessary illustrates a challenge for cognitive control that I have not addressed so far: the cognitive system faces the problem of having to reconcile two antagonistic demands (Goschke, 2003). On the one hand, controlled action implies that goals must be pursued in the face of distraction. Otherwise, behavior would be solely governed by incidental environmental stimulation or predominant habits. Easy tasks like completing a game of cards would then be interrupted by any occurring event that might demand a response, for instance your cat begging for food. On the other hand, goals and intentions are subject to change and behavior must be adjusted accordingly. Such flexibility warrants that – although your goal might currently be to win a game of cards – you could interrupt the activity to rise and leave the table when the doorbell rings. The balance between flexibility and stability is crucial to cognitive control but by no means constant. An influential theory proposes that affective states can modulate behavior to favor stability over flexibility or vice versa (Ashby, Isen, & Turken, 1999). For instance, positive affect is assumed to improve cognitive flexibility, possibly through an increase in dopamine levels. Likewise, and in the case of this thesis more importantly, task representations affect the stability of performance. Findings from social psychology show that representing future goals as context dependent if-then plans helps achieve these goals (Gollwitzer, 1993, 1999). According to this theory, *implementation intentions* link a desired outcome to a specific situational cue. As soon as the cue (the *if-part)* is encountered, the response (the *then*-part of the plan) is automatically activated. While sitting with your friends, you might remind yourself to make new ice cubes. But it is not unlikely that you would forget to do so the next time you entered the kitchen. Forming an implementation intention, for instance*, if I open the fridge to get out a beer then I will also fill the ice tray with water*, would increase the chances of actually ending up with ice cubes. Along these lines, Wieber, Von Suchodoletz, Heikamp, Trommsdorff, and Gollwitzer (2011) showed that school-aged children who used implementation intentions (e.g. "if a distraction comes up I will ignore it") rather than simple goal intentions (e.g. "I will ignore distractions") performed better under conditions of moderately or highly attractive distractions.

Differences in the representation of tasks are fundamental to this thesis. Its main focus is the interplay of two aspects from the wide and fascinating field of cognitive control discussed here: task representations and shielding from distraction. As will be outlined in more detail later, the way a task is represented affects distractibility by irrelevant information. Especially with regard to new associations between stimuli and responses instructions can differ in abstractness and generalizability. As will be elaborated on later, the distinction between abstract task representations in terms of categorization rules and simple stimulus-response mappings affects the stability of performance. Abstract tasks can be applied to a range of different stimuli that share a relevant feature or enable the same operation. In contrast, stimulus-response mappings are simpler, linking a specific object or event to a response without necessarily allowing for transfer or generalization. Going back to the game of cards you are playing with your friends (remember, it is a sunny Sunday afternoon), you might be told that the two of Hearts trumps, the five of Hearts trumps, the seven of Hearts trumps and so on. Alternatively – and in this example also obviously and less inexpertly – you could apply the categorization rule that *all Hearts trum*p. There is evidence that such abstract task rules which highlight the feature that is important for determining a response (in this case *suit of cards*), reduce the influence of irrelevant information. In contrast, exemplar-based learning of new mappings between stimuli and responses has no such effect. But before commencing with introductory findings on this topic, I will introduce the paradigm that first sparked interest in the question of how the representation of tasks in terms of categorization rules might benefit performance: the task switching paradigm.

TASK SWITCHING

There are a vast number of tasks that have been used to study various aspects of cognitive control. According to Norman and Shallice (1986) they involve planning, decision making, trouble-shooting, overcoming strong habitual responses, novelty, or danger and difficulty. For this thesis, one paradigm in particular is relevant. It was developed to study the ability to shift between different tasks and has been popular and fruitful for almost two decades. In the *task switching paradigm*, subjects usually switch between two or more different task sets (Rogers & Monsell, 1995), rules, mental sets (Jersild, 1927) or operations (Shaffer, 1965). The most typical finding is that performance on a task switch (i.e. the task in the current trial is different from the task in the previous trial) is slower and more error-prone than performance on task repetitions (i.e. performing the same task in two consecutive trials). Returning to the example from the beginning of the introduction, when having to take beverages outside to your friends you might have to prepare different kinds of drinks. According to findings from the task switching literature, preparing two iced coffees in a row should be easier than first preparing a cocktail and then turning to the iced coffee.

The task switching paradigm has been used frequently since 1994. The results are manifold, as are the interpretations. Giving a detailed review would be beyond the scope of this thesis. For comprehensive and current reviews the reader is referred to Vandierendonck et al. (2010) and Kiesel et al. (2010). Here, the history of the paradigm as well as selected current results will be discussed. The review of current results will focus on effects that are potentially relevant to the studies conducted for the present thesis.

THE HISTORY OF TASK SWITCHING

THE PIONEER (1927)

Most reviews on task switching cite Arthur T. Jersild's *Mental Set and Shift* (1927) as the first work to use the task switching paradigm (Dreisbach, Haider, & Kluwe, 2002; Mayr & Kliegl, 2000; Stoet & Snyder, 2007; Vandierendonck, Liefooghe, & Verbruggen, 2010; Waszak, Hommel, & Allport, 2003; Wylie, Javitt, & Foxe, 2006). The title *Mental Set and Shift* was borrowed from a book by Hollingworth and Poffenberger (1919, cited by Jersild, 1927) who – according to Jersild – were the first to comment on the ineffectiveness of frequently shifting between sets. Although at the time research on shifting tasks was already existent, Jersild claimed to be the first to study the effects of switching back and forth between elements of uncompleted tasks. Until then, shift paradigms had subjects switch from one already completed task to a new task and were used to study practice and interference or perseveration effects. Based on the reasonable assumption that frequent switching leads to performance costs Jersild set out to systematically study specific questions concerning these proposed detrimental effects: do costs occur irrespective of the nature of the tasks to be performed? Are these costs affected by task difficulty or practice? Is there a special ability to shift or is shifting performance related to general intelligence or other factors?

Jersild presented his participants with tasks of varying difficulty and relatedness. Subjects received lists of targets and had to work through these lists using a single task (*pure condition*; task A only or task B only) or using alternating tasks (*shift condition;* e.g. ABAB). For instance, a given subject might have had to add 6 to every number in a first list of double-digit numbers, subtract 3 from every number in second list, and then alternate between adding 6 and subtracting 3 in the remaining two lists. This setup allowed Jersild to measure performance in a single task context and in an alternating task context and compare these two conditions. He took the difference in time between the pure condition and the shift condition. This difference was then divided by the time needed to complete the pure condition. That way, the loss associated with shifting was directly related to the time it took to perform the tasks separately. This measure was called *per cent shift loss*.

Jersild varied the type and difficulty of tasks. In the first experiments, subjects had to perform mathematical operations on double-digit numbers. Some of these were easier than others. For instance, in Experiment 5 subjects had to *add 1* to or *subtract 1* from every number, while in Experiment 4 the tasks were *add 17* and *subtract 13*. Later, Jersild used additional tasks such as controlled associations, color naming, form naming, and simple counting.

His results can be summarized as follows: (a) In most experiments shifting caused costs that – at least for the calculation tasks – were inversely related to the difficulty of the tasks. The easier the task, the higher the per cent shift loss. The costs associated with shifting were measured for whole lists, but breaking them down by dividing them by the number of targets per list often resulted in a shift loss of several hundred milliseconds per item. (b) A shift loss was not always observed. If the targets were easily distinguishable, for instance, when subjects had to switch between calculations and associations (i.e. numbers and words), shifting caused a slight gain. Likewise, introducing external cues that directly indicated the task reduced the shift loss to only 2 %. When the stimuli in the shift condition were not presented in one uniform list but disambiguated by position (the targets of task A were presented on the left and the targets of task B on the right) the median shift loss was reduced to almost zero.

Jersild's choice of measurement and presentation would nowadays be considered inadequate for studying what has been termed the *task switch cost* (for reviews see Monsell, 2003;

Vandierendonck et al., 2010). He did not present the targets one by one, thus allowing for preview and consequently overlap in processing of the current and the following target. Moreover, reaction times were not measured individually for each item. Instead, the times needed to complete entire lists were collected. This procedure gave way to problems like the correction for errors in the two conditions or confounding the actual cost of a switch with factors such as remembering two tasks and keeping track of which one to perform (*shift condition*) vs. remembering only one tasks (*pure condition*). Jersild himself acknowledged that overlap and interference between tasks contributed to his results. In most current studies on task switching, this would be referred to as a mixed-list cost (e.g. Koch, Prinz, & Allport, 2005), that is, a drop in performance that is not solely caused by the process of shifting, but also by other factors.

Yet, Jersild is correctly cited as one of the earliest researchers to use a task switching paradigm. Although it might be doubted that he was actually the first [for instance, Meiran (2009) suggests that it was Jones (1915, cited by Meiran, 2009)], it was Jersild's research on which Allport, Styles, and Hsieh based their reintroduction of the task switching paradigm in 1994. Up until the last decade of the 20th century, research using the task switching paradigm was scarce to say the least. In this short historic review, I will focus on two studies that were conducted before 1994 (for more information on earlier studies see Meiran, 1996). The first study I chose, because it directly relates to Jersild's results. The second study – to the best of my knowledge – was the first to measure the difference between discrete task repetition and task switch trials within a single mixed task block.

SPECTOR AND BIEDERMAN (1976)

In 1976, Spector and Biederman set out to validate Arthur Jersild's results. For switching between calculation and association Jersild had found an advantage for the shift condition over the pure condition. Spector and Biederman intended to replicate this result and further identify the conditions under which shifting causes a drop in performance. However, the authors were not able to replicate the shift gain with Jersild's procedure. When subjects worked through lists of numbers and words, alternating between subtracting 3 and naming opposites, they were a little faster in the mixed condition but the difference was not statistically reliable. When the same targets were presented on separate cards instead of sheets (thereby essentially preventing preview) no shift gain was found. Yet, with the card procedure some preview was still possible when subjects turned the next card while still giving the answer for the current card. Therefore, in a second experiment, Spector and Biederman used a projector to show numbers and words in completely random order. A voice key measured the response time on every trial and the termination of the response led to the presentation of the next slide. This made preview impossible and led to a small but non-significant shift loss. The authors concluded that it was mainly the possibility of processing the next stimulus, while still responding to the current target that caused the shift gain in Jersild's experiments. In two additional experiments, Spector and Biederman replicated Jersild's finding that shift loss was greatly increased when the targets did not unambiguously cue the task. With only numbers as targets and subjects shifting between two calculation tasks a significant shift loss was found. This loss was still significant but greatly reduced when cues were added. These latter results are in line with Jersild's findings that external cuing improves performance and attenuates the switch cost.

In sum, Spector and Biederman replicated Jersild's findings for the most part. In one experiment (Experiment 2), the procedure was improved by using a projector and measuring discrete reaction times rather than the time it takes to complete an entire list. Still, the exact difference between repetition trials and switch trials within a block of task shift was not reported.

SHAFFER (1965)

To the best of my knowledge, the first psychologist to study the difference between single task repetition and task switch trials within a mixed task block was Shaffer (1965). Like Spector and Biederman, Shaffer referenced Jersild and his finding that shifting between similar operations (e.g. calculations) resulted in costs. Shaffer used an approach that is similar to today's task cuing paradigm. Tasks had to be applied in random order. The ambiguous targets were accompanied by cues that indicated which task had to be performed. The timing of cue and target presentation was varied and reaction time was measured on every trial. Targets were two horizontally arranged lights; two correspondingly arranged buttons served as response panel. There were two different mappings: a homolateral mapping, where the button corresponding to the side of the light had to be pressed, and a contralateral mapping, where subjects had to respond by pressing the opposite button. An illuminated cross located between the two lights served as cue. Two groups of subjects used the homolateral or contralateral mapping only, resembling Jersild's pure condition. The other subjects were allocated to one of four shift groups that differed in the relative timing of the onset of target and cue. Shaffer found that reactions times were faster in the pure conditions, thereby replicating Jersild's results of a general shift loss with ambiguous targets. In addition, he showed that within an alternation session, there was a main effect of task transition. Task shift trials were responded to more slowly than repetitions trials. This cost was found irrespective of the timing between cue and target.

Shaffer's results for the first time nicely demonstrated the difference between mixing costs and task switch costs. Overall, even for task repetitions in the shift condition subjects took about 300 ms longer than for trials in the pure condition (mixing cost). In addition to this overall cost of shifting came an extra cost associated specifically with switching the task, or in this case, the stimulus-response mapping.

It is interesting to note that although he did not specifically report it, Shaffer's results – in addition to the task switch cost – show another effect that is now commonly found in task switching studies: In his statistical analyses Shaffer only included stimulus transitions (repetition/switch of the target light) and task transitions (repetition/switch of the mapping rule). He found that the two types of transition did not interact. However, from the data reported one can easily extract reaction times for response repetitions and response switches. This shows that in all shift groups, response transition numerically interacted with task transition. For task repetitions, there was a response repetition benefit, whereas on task switches, response repetitions were slower than response switches. Unfortunately, from the data reported by Shaffer it is not possible to deduce whether this interaction was statistically reliable. Yet, this is an early illustration of a noteworthy result not specifically connected to the switch cost, which has since been found repeatedly. It implies a strong connection between a task, its stimuli and responses. Repeating a response might ordinarily be considered advantageous to performance, yet changing the context (in this case the mapping) reverses the benefit and sometimes even results in costs.

Today, the findings from the early studies on task switching discussed here are still investigated and debated upon. Especially the task switch cost – albeit assessed differently today – is a frequent source of dispute. Others focus on the effects factors such as preparation or cuing have on the switch cost. In addition, effects other than the switch cost, for instance Shaffer's unmentioned interaction between response and task are subject to investigation.

REDISCOVERY OF THE TASK SWITCHING PARADIGM

The three studies reported above constitute a selective review on task switching between the years 1927 and 1994. In general, studies on the topic were few and infrequent at that point. Therefore, to choose the term *rediscovery* for what happened to the task switching paradigm in the year 1994 seems warranted. Two studies employed the paradigm in different ways and came to different conclusions concerning switch costs. Research on the topic started to surge and typing the term *task switching* in databases now yields more than 1.000 results. Before typical findings from a selection of these studies are discussed, the pioneering work of Allport et al. (1994) and Rogers and Monsell (1995) will be presented shortly, as it lay the groundwork for current research on task switching.

THE TASK SET INERTIA ACCOUNT

In 1994 Allport and colleagues revived the task switching paradigm. Their study was the first in a line of published papers that led to a surge of experiments on different aspects and different interpretations of switching and the associated costs. Since by the 1990s research on the task switching paradigm had not been extensive, Allport et al.'s hypotheses concerning the switch cost were guided by assumptions rather than theory-grounded. Their initial goal was to study voluntary shifts of mental set as a marker of cognitive control operations. The rationale was based on theories of cognitive control that postulate a unitary system with limited resources. Therefore, additional demands on control such as increased difficulty of task or number of components to be switched between were expected to increase switch costs. These switch costs, in turn, should help gain more insight into the mechanisms of cognitive control.

Like Spector and Biederman (1976), Allport and colleagues started by using variations of Jersild's original paradigm. Reaction times for the completion of whole blocks were taken. Allport et al. used Stroop-like number and word stimuli. Number stimuli were identical numerals presented inside a rectangular frame (e.g. six times the numeral 3). They were multidimensional in that numerical decisions could either be based on the value of the numeral (three) or on the number of numerals inside the frame (six). Word stimuli were incongruent Stroop stimuli, that is, color words were printed in a color that did not match the word's meaning (e.g. the word GREEN printed in red ink). Different switch conditions were used: Subjects switched between operations (e.g. switching between a parity task and a magnitude task on numeral values), between stimulus dimensions (e.g. performing the parity task on the value of the numeral vs. the number of numerals within a frame), or between both (e.g. switching from the parity task on the numeral value to the magnitude task on the number of numerals). When word stimuli were introduced in Experiment 3, additional switch conditions were possible, including switching between dominant tasks (i.e. switching between word reading and naming the value of the numeral) and non-dominant tasks (i.e. switching between color naming and naming the number of numerals). Moreover, in Experiment 5, Allport et al. discarded the list method and introduced discrete, experimenter-paced trials that allowed manipulation of the inter-trial interval (ITI).

Starting out with the assumption that switching mental set is a characteristic of cognitive control, Allport and colleagues had expected to find that changing task difficulty and/or complexity of the switch (i.e. switching only the operation vs. additionally switching stimulus dimension) would result in increased switch costs. Based on theoretical models of cognitive control that emphasize capacity limitation and unity of the control system, factors such as number of features to be switched should have increased the demand for control and thus prolonged response times. Yet, to the authors' surprise, many manipulations had an overall effect on reaction times but did not interact with the switch cost. The additional time needed to complete shift lists compared to pure lists was unaffected by most factors.

These results made Allport et al. radically change their presuppositions about the connection between the costs associated with shifting and cognitive control. They argued that the switch cost could not reflect an intentional shift of set that precedes execution of a subsequent task or trial. Instead, they introduced the term *task set inertia* (TSI) to account for the difference in results between switch and repeat conditions. TSI refers to the notion that it is persisting activation of the preceding trial or – on a more general level – a task previously associated with a stimulus that leads to the costs associated with switching. Allport and colleagues based their suggestion on several results that seemed to be at odds with the idea of intentional advance task preparation. First and foremost, preparation time of up to 1100 ms (Experiment 5) did not eliminate and not even reliably reduce the switch cost. Yet, with a predictable task sequence, introducing ITIs that were larger than the average switch cost should have eliminated any costs if they purely reflected a cognitively controlled shift operation. Moreover, Allport et al. found almost symmetrical Stroop interference for word reading and color naming in a shift condition. The Stroop effect (for a review see MacLeod, 1991) is usually found to be asymmetrical, that is, interference is reliable in the non-dominant task (e.g. word meaning interferes during color naming) but not in the dominant task (print color does not interfere with reading). Thus, interference during word reading points at persisting activation of the color naming task. Another prominent result that the authors found hard to reconcile with an account of advance preparation is the asymmetrical switch cost observed for switching between word reading and color naming. Subjects showed large switch costs when shifting from the non-dominant task (color naming) to the dominant task (word reading), but not vice versa. This result is somewhat counterintuitive. If the switch cost reflects a cognitive control mechanism responsible for shifting, then surely disengaging from the non-dominant task and activating the dominant task should be easier then the reverse condition. Consequently, this result poses a problem for an advance preparation account. However, with TSI, Allport and colleagues managed to find an explanation: the non-dominant task requires a more strongly imposed set in order to prevent interference from the dominant task. In turn, the dominant task might have to be inhibited for the same reason. As a consequence, TSI from the non-dominant task is stronger resulting in larger switch costs.

It must be noted though, that although Allport et al. attributed the switch cost to retroactive adjustments in terms of TSI rather than to a proactive control process, they did not deny that such a control mechanism exists. Rather, they assumed that switch costs do not directly measure cognitive control, since TSI is sufficient to account for them.

The Reconfiguration View

In 1995, Rogers and Monsell disagreed. They chose a different approach to the task switching paradigm. Unlike Allport et al. (1994) or Spector and Biederman (1976), Rogers and Monsell (1995) used discrete reaction times and refrained from applying the list procedure because of its many disadvantages. Instead, they introduced the alternating runs paradigm: Subjects predictably switched between pairs of tasks (e.g. AABBAA etc.). Additional external cues in terms of spatial location (the target's position in a 2 X 2 grid) were used. Within a run of four trials, two task repetitions and two switches occurred. The tasks were to decide whether a numeral was odd or even (task A) or whether a letter was a consonant or a vowel (task B). In most trials, one numeral and one letter were presented side by side. This resulted in crosstalk between the tasks, because the target from the relevant task was accompanied by a target from the competing task. In some trials, the irrelevant character (i.e. the numeral in the letter task or the letter in the numeral task, respectively) was replaced by a neutral character (e.g. %) creating a condition without crosstalk.

Rogers and Monsell conducted six experiments. Their results mirror many aspects of previous task switching studies: They found that switch trials were responded to more slowly than repeat trials (Spector & Biederman, 1976; Shaffer, 1965). Moreover, the cost associated with switching was smaller for univalent targets, that is, targets that unambiguously cued the task (Jersild, 1927; Allport et al., 1994). Also, preparation reduced the switch cost but did not eliminate it (Allport et al., 1994). However, considering all 6 experiments, Rogers and Monsell's interpretation differed profoundly from Allport et al.'s TSI account. Specifically, they interpreted their results as being non-consistent with TSI. One of the main arguments against the idea of a purely passive carryover effect of the previous task is that only the first trial following a switch was slowed. After that, a considerable improvement occurred from the first to the second trial and no further improvement was found for the second and third repetition. Rogers and Monsell argued that a process like TSI should have persisted over more than one trial, gradually exerting less influence. Moreover, the authors found that preparation reduced switch cost reliably, yet only when the response-stimulus-interval (RSI) was varied between blocks (as opposed to within a single block). A passive process like TSI, they argued, should not be affected by whether the time for dissipation is varied within or between blocks. Therefore, they proposed that switch costs reflect the *reconfiguration* of the cognitive system which enables the implementation of the relevant task that has to be switched to.

Overall, both Allport et al. and Rogers and Monsell found that preparation reduces the switch cost. Yet, they reached different conclusions regarding the interpretation of this result. Allport et al. found the reduction to be non-significant and took this as a point against the idea of advance endogenous preparation. In contrast, Rogers and Monsell found the difference in switch cost for short and long preparation intervals to be significant and hence indicative of a controlled, preparatory process. In sum, the studies by Allport and colleagues and Rogers and Monsell differ in many aspects including the tasks, the paradigm, time measurement and most important, the interpretation of the results concerning the mechanisms responsible for the switch cost. To date, almost 20 years of research on the task switching paradigm later, it is still debated what process exactly the costs reflect. To be clear, Allport et al. did not deny that reconfiguration was necessary, and neither did Rogers and Monsell refute the idea of proactive interference from the previous trial [Monsell (1996) even acknowledges that the exogenous component they postulated might in fact resemble TSI]. However, the authors disagree on what is measured by the switch cost: TSI or reconfiguration.

TYPICAL EFFECTS IN THE TASK SWITCHING PARADIGM

The debate on the switch cost continues, and with it research using the task switching paradigm. This has led to a number of additional findings that are worth further investigation. Task switching has proven to be more than the study of switch costs. Some of the most prominent findings which are relevant with respect to Part III and Part IV of the present thesis will be presented below.

THE TASK RULE CONGRUENCY EFFECT

Task switching studies are usually designed to study flexible behavior. Yet, they also allow one to draw conclusions concerning the stability of task representations or intentions. Crosstalk effects (e.g. Rogers & Monsell, 1995) illustrate how currently inactive but still potentially relevant tasks affect performance. Although subjects usually successfully switch and settle for one task at a time, competing associations or tasks are a potential source of interference. In 1987, Sudevan and Taylor provided evidence that the influence of mappings from a competing task is not confined to switch trials. They let participants switch between two digit categorization tasks (odd/even vs. low/high). Responses were given manually with one of two response keys. For odd and low numbers the left-hand key had to be pressed. Even and high numbers were mapped to the right-hand key. This way, compatible and incompatible stimuli were created: Compatible stimuli were digits that were mapped to the same response in both tasks, whereas incompatible stimuli were mapped to different responses. For instance, the digit *3* is odd and low and therefore would always require a left-hand key press. In contrast, the digit *7* is odd and high, which would indicate the left key in the odd/even task but the right key in the low/high task. Sudevan and Taylor found that in the odd/even task, responses in compatible trials were faster than responses in incompatible trials. This effect was somewhat reduced by practice but only with inter-stimulus intervals (ISIs) of 1200 ms and more. With small ISIs, even after 20 days of practice the effect was still pronounced.

The compatibility effect Sudevan and Taylor described in 1987 is a robust finding in task switching experiments. It is mostly referred to as the task rule congruency effect (TRCE). When subjects switch between tasks, mappings form the currently irrelevant task affect performance in the relevant task such that congruent[1] trials are typically responded to faster than incongruent trials. The TRCE might be seen as reflecting the activation of two competing rules in working memory where the currently irrelevant rule interferes with the execution of the relevant rule. However, it does not seem to be affected by concurrent working memory load (Kessler & Meiran, 2010; Kiesel, Wendt, & Peters, 2007; Meiran & Kessler, 2008). Kiesel et al. (2007) provided evidence that loading working memory (WM) does not reduce the TRCE. Memorizing a list of two (low WM demand) or five (high WM demand) letters while switching between two digit categorization tasks (odd/even vs. low/high), had an effect on overall response times but did not interact with the congruency effect. That is, overall, subjects' responses were slower when they had to memorize five letters but the congruency effect was not affected by this increase in WM load. Kiesel and colleagues reasoned that the high load condition should have affected the size of the TRCE if the effect was due to the active representation of the competing task in WM. This was clearly not the case. Kessler and Meiran (2010) extended these findings by showing that even loading WM with additional task rules (as opposed to the simple memorizing of task-unrelated letters) did not affect the TRCE. In addition to shifting between a color and a shape judgment task subjects either also had to perform one to three numerical tasks (Experiments 1 and 2) or additional visual tasks (Experiment 3). Like Kiesel et al. (2007) the authors found no effect of WM load on the TRCE. Therefore, Meiran and Kessler (2008) proposed that the TRCE results from activated codes in long term memory (LTM). The authors found a TRCE with existing response codes (e.g. up/down), but not with novel response categories. More specifically, subjects had to respond to the location of a target in a 2 X 2 grid. Arrows served as cues and indicated along which axis a spatial judgment had to be made. When participants switched between the two classical spatial tasks *up* vs. *down* and *left* vs. *right*, a robust TRCE was found. For instance, when *up* and *left* were mapped to the same response key a target in the upper left corner was responded to faster than a target in the upper right corner. However, when the display was slightly rotated, the well-known response codes *up*, *down*, *left*, and *right* could no longer be used. Instead, novel response codes had to be generated and the TRCE disappeared. This led Meiran and Kessler to propose that the existence of abstract response category codes in activated LTM is a prerequisite for

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[1] The match or mismatch of targets, distracters and/or responses is sometimes referred to as compatibility, at other times as congruence or congruency. Hommel (1997) uses the term congruence to describe a match/mismatch between two stimuli (stimulus-stimulus congruence; e.g. the STROOP effect) whereas compatibility implies that the match or mismatch is found between stimuli and responses (stimulus-response compatibility; e.g. the Simon effect). However, this terminology is not consistently applied in the studies discussed here. This usually does not pose a problem, since only one source of interference due to match/mismatch is present, thus making the meaning apparent from context. For reasons of consistency, I chose the term congruency in all experiments conducted for this thesis (because a separate stimulus served as distracter). However, in the introduction, I report the term as given by the authors of the cited study. Thus, compatibility and congruency/congruence are used interchangeably.

the TRCE. Activated LTM thereby refers to a model of working memory (Cowan, 1988; Oberauer, 2001) that distinguishes between a capacity-limited focus of attention (FOA), and activated representations in LTM, which are not subject to severe capacity-limitations. In a similar vein, Mayr and Kliegl (2000) suggested that the TRCE arises from the retrieval of response codes from LTM rather than simultaneous activation of task rules in WM. When the stimulus is presented it cues the retrieval of the corresponding relevant and (currently) irrelevant responses. This retrieval results in interference if the responses do not match. Results from Yamaguchi and Proctor (2011) fit well with this account. These authors posit that active maintenance of the competing SR mappings is not necessary for the TRCE. They found that even in a condition where subjects did not randomly switch between tasks but performed the tasks in a blocked sequence one at a time a TRCE occurred. This is in line with the assumption that the interfering rules need not necessarily be kept active in WM (presumably, in the blocked task condition the irrelevant rules were unloaded from capacity-limited working memory), in order for congruency effects to occur.

However, the degree of activity of the competing task or mappings, respectively, seems to have some influence on the TRCE seeing as the effect is sometimes larger on switch trials than on repetition trials (e.g. Koch & Allport, 2006; Meiran & Kessler, 2008) On the other hand, competing task sets need not have been carried out recently in order to result in congruency effects. The mere instruction of a task can result in a TRCE, provided that subjects expect that task to be relevant at some point (e.g. Liefooghe, Wenke, & De Houwer, 2012).

INHIBITION

The task set inertia account first proposed by Allport et al. (1994) implies that in order to successfully perform the current task, the competing task must be inhibited to some degree to overcome the persisting activation. As soon as the subject has to switch back to the previously suppressed task, this inhibition should contribute to the switch cost. However, comparing performance on switch and repeat trials makes it impossible to disentangle priming effects from inhibition. When subjects perform better on a task repetition than on a task switch this could be due to priming of the relevant task on repetition trials *or* impeded reactivation of the previously inhibited task on switch trials. Mayr and Keele (2000) introduced a paradigm that cleverly deals with this issue. In order to investigate the inhibition of an abandoned task rule, they compared performance on trials where the same task had been performed recently to performance on trials where that task had been performed less recently. The authors reasoned that inhibition should decay with time, so the more recently a task had been abandoned (and hence suppressed) the more strongly it should be inhibited. Subjects in Mayr and Keele's experiments switched between three tasks A, B, and C. The third trial in one of two possible sequences was studied. In an ABA sequence, subjects had to switch from task A to task B, and then back to task A. In contrast, in a CBA sequence, the last execution of task A took place longer ago. Consequently, task A was expected to be less inhibited than in an ABA sequence. Mayr and Keele predicted worse performance on the third trial in an ABA sequence compared to a CBA sequence. The results fit this prediction. The supposed inhibition of a previously abandoned task set was called *backward inhibition*. It is sometimes more descriptively referred to as *lag-2 repetition cost.* Mayr and Keele found that backward inhibition is an endogenously driven control process. Only when cues informed participants about the upcoming task were ABA trials responded to more slowly than CBA trials. With a bottom-up setting where the relevant dimension was directly indicated by the target and task sequence was not predicted by cues, no backward inhibition was found. This fits well with results from Dreisbach, Haider, and Kluwe (2002, Expermients 4 and 5), who used cues to indicate the probability of a task repetition or a task shift (e.g. 75% probability for a task shift, 25% probability for a task repetition). They found that the improbable task was inhibited (as indexed by slow reaction times to unexpected tasks), but only if subjects knew which task to activate instead (there were four possible tasks). More precisely, if subjects knew that a switch was probable, and also knew which task they would (probably) have to switch to, the preceding task was inhibited and the expected task was activated. However, if a switch was probable but no information was given as to which task would be switched to, no inhibition occurred. This latter condition resembles the stimulus-driven switching procedure studied by Mayr and Keele.

The term lag-2 repetition cost implies that inhibition of the previously executed task is detrimental to performance. However, Hübner, Dreisbach, Haider, and Kluwe (2003) showed that backward inhibition can also enhance performance. They applied a task switching paradigm with three tasks. The setup resembled the flanker task (Eriksen & Eriksen, 1974), that is, the target stimulus was always flanked by two distracters from one of the competing tasks. Hübner and colleagues reasoned that backward inhibition of the previous task should reduce interference by that task in the current trial. Distracter interference should be low if the flanker stimuli were associated with the just abandoned task because that task would still be inhibited. Results were as predicted: On switch trials, flanking stimuli from the preceding task interfered less than flanking stimuli from the control task. This indicates that the preceding task set was inhibited when a switch was required. Moreover, like Mayr and Keele (2000) and Dreisbach et al. (2002), Hübner et al. report that inhibition of the preceding task set was only found if informative cues were used. Without indication as to the identity of the upcoming task interference from flankers from the preceding task was higher than interference from control task flankers.

In sum, although the matter is still disputed (see e.g. Lien, Ruthruff, & Kuhns, 2006), it seems probable, that a task switch is supported by the inhibition of the previously relevant task. However, this backward inhibition depends on the availability information indicating the identity of the upcoming task.

For the sake of completeness it must be noted that in task switching inhibition is not only found as a consequence of the switch per se. While Mayr and Keele (2000) as well as Hübner et al. (2003) studied task set inhibition resulting purely from task sequence (inhibition due to a switch of task), Meiran, Hsieh, and Dimov (2010) showed that a task need not be abandoned (i.e. switched from) in order to be inhibited. If a competing task generates response conflict in an incompatible trial, this task is inhibited. If the previously interfering task then becomes relevant, this inhibition results in response slowing. Meiran et al. termed this effect *competitor rule suppression*. Unlike the TRCE it is not assessed in a single trial but relies on response-interference in the preceding trial. Moreover, unlike backward inhibition, competitor rule suppression is only found if the response generated by the competing task is incompatible with the response of the currently relevant task. The idea that the strength of inhibition depends on the amount of interference caused by a task was also put forward by Goschke (2000). He reported that switch costs were increased following incongruent trials, indicating that the response conflict led to selective inhibition of the interfering stimulus dimension or task.

PREPARATION EFFECTS

Prolonging the time to prepare for an upcoming trial often reduces the switch cost (Meiran, 1996; Rogers & Monsell, 1995), although it is seldom completely eliminated (for exceptions see Hunt & Klein, 2002; Verbruggen, Liefooghe, Vandierendonck, & Demanet, 2007). Carryover accounts can easily explain preparation effects as well as the residual cost by assuming that activation dissipates with time but there is still some interference to be overcome when the target is presented (but see e.g. Rogers & Monsell, 1995, for preparation effects that are problematic to explain for carryover accounts). In contrast, residual costs are not easily explained by an active process of preparation. It is not easy to see why prolonging preparation time beyond the usual switch cost should not completely eliminate this cost. Additional assumptions have to be made in order to account for the lack of complete elimination of the switch cost. Some authors explain the reduction of switch cost in terms of an endogenous act of reconfiguration (Rogers & Monsell, 1995), for instance by loading the current goal into working memory (*goal shifting*; Rubinstein et al., 2001) or biasing the input in favor of currently relevant features (Meiran, 2000). The remaining residual cost is assumed to be caused by the inability to fully prepare for a switch endogenously. More specifically, a second component of task switching, for instance retrieving the relevant stimulus-response translations (*rule activation*; Rubinstein et al., 2001) or biasing the response set (Meiran, 2000) can only be completed *after* stimulus presentation. The residual costs are attributed to this additional component of task switching. Others do not assume that complete preparation is impossible. For example, the *failure-to-engage* hypothesis put forward by De Jong (2000; for a similar account see Lien, Ruthruff, Remington, & Johnston, 2005) proposes, that preparation is successful on some trials, but not on others. Performance on task switches reflects fully prepared switches as well as switches where preparation failed. The latter are the cause of the small residual cost.

Importantly and notwithstanding the residual cost, time to prepare does have beneficial effects on switch trials. Of course, preparation depends on the subjects' knowing which task to perform next. This prior knowledge can either be conveyed through cues (e.g. Meiran, 1996) or by informing subjects about task sequence, for instance by using alternating runs (e.g. Rogers & Monsell, 1995). Both, prolonging the RSI (with alternating runs) as well as prolonging the cue-stimulus interval (CSI) when cues are used reduces the switch cost.

On a side note concerning the use of cues, caution is warranted when interpreting the switch cost. Logan and Bundesen (2003) suggested that in the case of cued task switching the switch cost might not reflect an endogenous effect of preparation but rather a repetition benefit for the cue. On task repetitions cue and task are repeated, whereas on task switches both change. As a consequence, with only two cues, switch of cue and switch of task are perfectly confounded. Using four cues (two cues per task), Logan and Bundesen found that subjects benefited from a task repetition only when the cue was repeated, too. A mere task repetition that was accompanied by a cue change did not lead to a significantly improved performance over task switches (and consequently also cue switches). The authors proposed that in the case of cued task switching it is not necessary to postulate a shifting process. Rather, results can be explained by assuming that subjects use a compound cue-stimulus-response retrieval strategy. The combination of cue and target uniquely defines the response and makes switching unnecessary. Logan and Bundesen's results have been replicated and extended (Arrington & Logan, 2004), however, some studies provide evidence that there might be more to switch costs than a mere switch of cue after all (e.g. Altmann, 2006; Mayr & Kliegl, 2003). In any case, results show that caution is necessary in the interpretation of results from the cued task switching paradigm.

Although the effects of preparation are most often discussed with respect to switch trials, there is reason to believe that task repetitions also benefit from long preparatory intervals (e.g. Poljac, Haan, & van Galen, 2006). Rogers and Monsell (1995) reported that prolonging the RSI reduced RTs in switch and repeat trials alike. Moreover, using the cuing paradigm, Altmann (2004) found that only a manipulation of the CSI within subjects reduced the switch cost. Manipulating preparation between subjects affected both switch and repeat trials, that is, with a between subjects manipulation length of CSI and size of the switch cost did not interact. Apparently, the often reported strong effects of preparation time on switch trials are dependent upon the specific experimental design. Moreover, concerning preparation, task repetitions seem to have an advantage over switch trials in that subjects implicitly expect them. Dreisbach et al. (2002) manipulated expectancies by showing cues that indicated whether a task switch or a task repetition was more probable. They found that RTs were slower in switch trials than in repetition trials and that probable transitions were answered faster than improbable transitions. However and importantly, probability and transition type (switch vs. repetition) did not interact. This fits well with results from a study by Sohn & Carlson (2000) who found that switch costs and effects of foreknowledge of a task were additive. Foreknowledge decreased response latencies but had no effect on the size of the switch cost per se.

In sum, it seems that the benefits of preparation are not specific to task switches. That is not to say that switch-specific processes are non-existent or not affected by preparation. However, the reduction of switch costs with preparation cannot be fully attributed to a switch specific process that can be configured in advance. Moreover, when cues are used, preparation effects should be interpreted with care.

RESPONSE REPETITION AND RESPONSE ALTERNATION EFFECTS

In simple choice RT tasks responses are typically faster when the response (Bertelson, 1965) or the stimulus category (e.g. Campbell & Proctor, 1993; Pashler & Baylis, 1991) is repeated in two consecutive trials. Apparently, all other things being equal, subjects' performance benefits from repetitions. However, this benefit is easily reduced or even reversed by changes in relevant or irrelevant stimulus features or shifts of task (e.g. Kleinsorge, 1999; Notebaert & Soetens, 2003; Rogers & Monsell, 1995). Rogers and Monsell (1995) reported that in all but one experiment, a task switch abolished and sometimes reversed the benefit of a response repetition. They offered three explanations for this surprising result.

The first explanation is a learning mechanism that affects the associative strength between stimulus attributes and responses. Responding to an attribute increases the associative strength between that attribute and the response, whereas the associative strength between any other attribute and the response is decreased. These changes in associative strength are subject to decay but they affect performance on the immediately following trial: Giving the same response is facilitated when the relevant attribute repeats (response repetition benefit on task repetitions), but it is impeded when the relevant attribute is now the one for which the link to the response was weakened (no response repetition benefit on task switches). As an example consider subjects switching between a parity task and a magnitude task where *odd* and *high* are mapped to the left response key. Responding to an odd number in the parity task strengthens the link between *odd* and *left*, while at the same time the link between *high* and *left* is weakened. When the task repeats another odd number would benefit from this strong link, whereas with a change of task the temporarily weakened link between *high* and *left* would impede performance. In the same vein, the theory of event coding (TEC) proposed by Hommel, Müsseler, Aschersleben, and Prinz (2001; see also Hommel, 1998) suggests that co-occuring perceptual and action features (i.e. stimuli and responses) are bound into an *event file*. When the same features are repeated, this binding helps retrieve the correct response. In contrast, when the same response is required with another stimulus or feature, it first has to be unbound from the previous event file, which imposes a cost. According to TEC, the likelihood for a stimulus to be integrated in an event file depends on task relevance (Hommel et al., 2001; Hommel, 2005). Task-relevance is thereby not easily defined and may include features sharing a dimension with the target or the responses or even simply the saliency of a given stimulus. In any case, this task-dependent *intentional weighting* keeps the likelihood for some stimuli or features to be included in an event file low.

The second explanation Rogers and Monsell suggest attributes the lack of a response repetition benefit on task switches to a control mechanism that – in the course of a task switch – suppresses all active responses. That is, with a shift of task the response that was just executed is inhibited, such that performance on a trial that requires a response repetition suffers interference.

The third account is very similar to this idea but it assumes a general response suppression mechanism rather than shift-specific inhibition. In order to prevent erroneous re-execution of the same response every response is inhibited after it has been executed. On a repetition trial inhibition of the response and the benefit of the repetition of the identical category-response mapping sum up to a repetition benefit. In contrast, on a task switch response suppression is not compensated for by a repetition of the mappings, and so performance on a response repetition trial is impeded (see also R. Hübner & Druey, 2006, 2008).

The abolishment or reversal of response repetition benefits is not confined to shifts of task. Response repetitions can also induce costs when the response category (Campbell & Proctor, 1993; Kleinsorge, 1999) or even an irrelevant stimulus feature is changed (Notebaert & Soetens, 2003). In a serial reaction time task Notebaert and Soetens (2003) let participants react to the color of a target stimulus, while spatial location (Experiment 1) or the target's shape (Experiment 2) served as irrelevant stimulus information. They found a response alternation effect in both experiments. A switch of the irrelevant feature was accompanied by an advantage for response alternations. However, in Experiment 2 this effect was confined to error rates. The authors explained the response alternation affect by assuming that a change in an irrelevant feature triggers a response switch. They argued that spatial location is a more salient feature than shape and a switch thus should affect the bias to alternate the response more strongly.

For response alternation effects the overlap between trials need not necessarily be physical, such as in the study just described. There is also evidence for interactions between an internally represented dimension and the response. Kleinsorge (1999, Experiments 1 and 2) let participants react to symbols and letters. There were no rules to be switched between, just single stimulus-response mappings (e.g. *diamond* → right-hand key; *H* → left-hand key). A category switch (a letter following a symbol or vice versa) was accompanied by a response repetition cost that was especially pronounced in error rates (see also Rogers and Monsell, 1995). Kleinsorge concluded that a switch in any dimension that is part of participants' task representation negatively affects the response repetition benefit and can turn it into costs.

Interestingly, what is part of participants' task representation and what is not is not easily predictable. As will be outlined in the next section the specific task representation seems to be crucial. Depending on the instruction subjects are affected differently by irrelevant features. If the instruction enables a categorical task representation, features deemed irrelevant by this instruction do not interact with the response. In contrast, when the instructions are given in terms of separate stimulus-response mappings without highlighting specific relevant features, the entire stimulus seems to become part of the task-representation such that response alternation effects are observed even for irrelevant features.

TASK SWITCHING: A SUMMARY

The controversy started by Allport et al. and Rogers and Monsell, whether switch costs measure proactive control or priming processes is still not solved. Most researchers would agree that the switch cost has more than one cause, very probably including carryover effects from previous trials, stimulus-specific priming, and the advance setting of parameters. However, the weight of the contribution of these factors in the eventually observed cost is still debated upon.

Likewise, other task switching phenomena, like the effects of preparation, the TRCE, or response alternation effects are still not unequivocally explained, nor even consistently found. The present thesis is not aimed at contributing to solving these controversies. However, the questions that spurred research on the current issue are grounded in the literature on task switching. It provides the background to the research that motivated this thesis, as will be outlined below.

THE SHIELDING FUNCTION OF TASK SETS

A question that inevitably emerges when one uses the task switching paradigm is why something as adaptive as using a task results in costs. This question goes beyond merely asking what causes the switch cost. Irrespective of whether it is the consequence of persisting task activation or reconfiguration, it seems odd that there is such a robust negative side effect of adopting more than one task set. After all, in everyday life *not* switching between tasks is the exception. Think of the last time you dedicated your time to one task only, without interruption, for a long period of time. If something comes to mind, I congratulate you: You might have found the exception that proves the rule. It is more common to frequently disrupt or change activities, for example for basic urges like hunger, or for environmental stimulation like a ringing telephone. Why then does switching come at a (very robust) cost? Looking back at the phenomenon of backward inhibition, one might infer that the cost is only one side of the coin. Remember that backward inhibition results in slowed responding in an ABA sequence compared to a CBA sequence due to persisting inhibition of task A. On the other hand, as shown by M. Hübner et al. (2003), backward inhibition has the positive effect of reduced interference by distracters from task A. Along the same line, one might conclude that the cost induced by switching tasks is merely a negative side effect of an otherwise advantageous strategy. Do task representations in terms of rules (as expected in task switching studies) offer some sort of benefit in spite of the switch cost? In order to assess the consequences of using and switching between rules, one must compare the use of task sets to alternative strategies. Only then can the advantages and disadvantages of rules be understood. For instance, might these representations be particularly stable (which usually a desirable state) and thereby possibly contribute to the switch cost when they have to be abandoned?

TASK SETS VS. STIMULUS-RESPONSE-MAPPINGS

Task switching studies are seldom equipped to answer question concerning such positive effects of task sets. For many years switch costs have been studied without looking into the task representations that enable them in the first place. In task switching studies it is assumed that subjects adopt two or more task sets/rules that are represented separately and consequently switched between. Yet, there are alternative approaches. In most experiments the number of potential target stimuli and responses is small, introducing the possibility of applying single stimulus-response mappings (SR mappings) instead of two alternating rules. For instance, if the tasks were to decide whether a number was odd or even and whether a letter was a consonant or a vowel, the targets might be 1, 2, 8, and 9 and A, B, O, and P respectively. In task switching, it is assumed that subjects comply with the instruction and use the rules, meaning the letter A would be identified as indicating the consonant/vowel task, and would then be categorized as a vowel, which in turn would lead to the activation of the appropriate response, for instance pressing the left response key. However, with such a small number of target stimuli subjects might just as well adopt a different strategy, namely learning eight separate SR mappings (see Figure 1). This would result in skipping the categorization process and directly associating the letter A with the left response key. The assumption that subjects switch between tasks is usually right (but see Logan & Bundesen, 2003, 2004), since switch costs are a robust phenomenon. But the question remains why subjects do not resort to the SR strategy and what would change in their performance if they did. In sum, the critical distinction here is between learning associations between stimuli and responses by heart, and learning a rule which provides information about the relevant response feature (as is assumed in most task switching studies). Returning to the example from the beginning, your friends might need a refill on their drinks. Suppose all women are having white wine, whereas all men are drinking beer (admittedly, this is example plays on stereotypes). This would correspond to a categorization process: you categorize your friend as male/female and then serve the appropriate drink. Alternatively, you could memorize a number of separate associations between names and preferred drinks (e.g. Alex → beer, Susi → wine, Peter → beer etc.), without noticing that gender is the important factor.

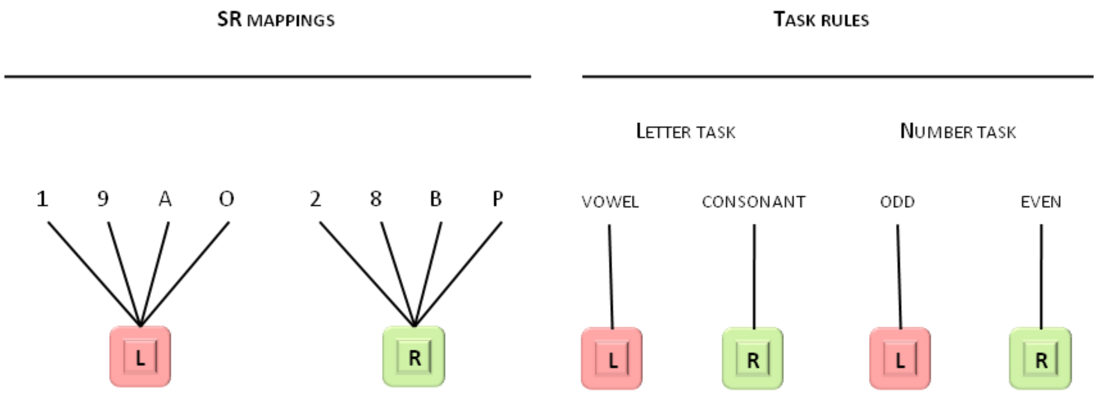

Figure 1. *Examples for task representations in terms of single mappings (SR mappings) or two task rules (adapted from Dreisbach, 2012). The SR representation consists of eight stimulus-response mappings, whereas the task rule representation offers four category-response mappings. (L = left response key, R = right response key).*

Of course there are obvious reasons, why – outside the context of experimental paradigms – abstract rules are preferable over arbitrary SR mappings. Jersild stated „that a mental set makes for economy of effort, that it serves to induce relevant, and exclude irrelevant reactions[…].” (Jersild, 1927, p. 49). A rule can be applied to a large number of stimuli, whereas memorizing single SR mappings would soon overcharge working memory capacity. Put differently, a rule highlights a relevant feature and can therefore easily be transferred to new stimuli and different contexts. An SR strategy would require every new stimulus to be memorized and would thus be the more effortful way of learning.

Yet, although rules most certainly offer an advantage over SR learning in real life situations, apparently they do not do so in the task switching paradigm. Consider a child reaching for a green cherry on a tree. A parent might tell the child that this specific cherry will not taste good because it is not ripe (SR) or it might say that most green fruit are not ripe and therefore not edible (TS). In this case, there is a probability that the child will encounter other green fruit and then make use of the rule. Hence, the rule is preferable over the SR approach. On the other hand, in an experimental context there is mostly no need to be prepared for transfer. The targets are known and a strategy can be chosen accordingly. So the question remains: why do subjects opt for rule use? What are the differences in performance with these two kinds of representations? For instance, one would not expect switch costs for the SR approach. There are no rules to be switched between so switch costs should disappear. Are subjects in task switching studies using rules because they are merely strictly following instructions? Can rules – once they are learned – not be un-learned? Or is there an advantage of rule use that might be concealed by the setup of task switching studies?

In 2007, Dreisbach et al. addressed these questions and for the first time directly compared groups of subjects that used either task rules or SR mappings. The study's main concern was whether rules would be applied if the experimental setup implicitly invited subjects to use an SR strategy instead. In addition, it addressed the question whether subjects would prefer rule use even if they had already learned the underlying SR mappings by heart. The author's approach was simple: Targets were four green and four red words. Each target word was uniquely associated with one of two response keys. This allowed the use of eight separate SR mappings for the task. Alternatively, the words could be associated with the responses according to two rules: If the target was printed in red, words starting with a consonant afforded a left key press and words starting with a vowel afforded a right key press. If the word was printed in green, animals were associated with the left key and non-animals with the right key (see Table 1).

Table 1. *Stimuli and tasks used in Experiment 1 of the study by Dreisbach et al. (2007). Words were introduced stepwise, two per block (adapted from Dreisbach et al., 2007).Translations are added in parentheses in the last column.*

Task	Response	Block 1	Block 2	Block 3	Blocks 4-6
consonant/vowel	Left	Bett	Bett	Bett	Bett (bed)
		-	-	Sieb	Sieb (colander)
	Right	-	Arm	Arm	Arm (arm)
		-	-	-	Eis (ice)
animal/no animal	Left	-	Rabe	Rabe	Rabe (raven)
		-	-	-	Igel (hedgehog)
	Right	Haus	Haus	Haus	Haus (house)
		-	-	Uhr	Uhr (clock)

One group of subjects was informed about the rules from the beginning (*early information condition*). A second group started by learning the SR mappings and practiced these for four blocks. After block 4, they were informed about the underlying rules (*late information condition*). This information was given casually without explicitly asking the subjects to start using the rules. After this, the subjects completed the two last blocks. A third group of subjects was never told about the rules but used the separate mappings throughout the experiment (*uninformed condition*). Overall, all subjects responded to the same targets with the same mappings but they represented the tasks differently (rules vs. individual SR mappings). In order to suggest the use of SR mappings even to the subjects informed about the rules the words were introduced stepwise, two at a time. This slow introduction of words was chosen to maximally encourage participants to learn separate mappings instead of applying the rules, without explicitly telling them to do so.

Dreisbach et al. (2007) studied the effects of information condition (early information, late information, uninformed) and block (1-6) on switch costs. Switch trials were defined as trials in which the color of the target changed. In the early information condition this color switch indicated a task switch, whereas to subjects using SR mappings the color should convey no information. If subjects in the early information condition used the rules despite the possibility to learn SR mappings instead, switch costs would be expected. For subjects using SR mappings no switching and hence no costs should occur.

The results were straightforward and left little doubt that rules are applied once they are known. First, subjects in the early information condition showed switch costs, indicating that they alternated between the instructed rules instead of basing their responses on eight individual mappings. Second, this was done although it was clearly possible to learn the mappings by heart, as indexed by the successful performance of the uninformed group. In fact, in Experiment 1 subjects in the late information and uninformed conditions were significantly faster than subjects in the early information condition. Experiment 2 revealed that this advantage disappeared when long target words (four syllables) were used. The use of short words might have made the experiment simple enough to give an advantage to the SR strategy over the more complex switching strategy. The third result concerns the late information condition. Here, subjects had already practiced the SR mappings and successfully applied them in four blocks. Only after block 4 did they receive information about the rules. Interestingly, they showed significant switch costs in block 5 which disappeared again in block 6. This was taken as evidence that, although subjects had previously successfully based their performance on SR mappings and were not specifically instructed to start using the rules, they still did. This can be inferred from the switch cost, since subjectively when questioned after the experiment subjects in the late information condition reported not having used the rules about which they had been informed casually.

The findings from this study show that using rules seems preferable over applying separate mappings even if subjects are implicitly invited to adopt a different strategy. The authors themselves give some explanations as to why this might be the case in the specific experimental setup. For instance, subjects in the early information condition did not know how many stimuli to expect, which might have prompted them to continue using the rules in case memorizing individual mappings would become too much with increasing set size. From this perspective, rule use might underlie intentional control, that is, participants in the informative condition used the rule because they were hoping to benefit from it but they could also have intentionally refrained from doing so. In contrast, participants in the late information and uninformed conditions had no choice but to learn every mapping separately. An alternative explanation refers to episodic retrieval of rules. When a stimulus is first presented and a rule is applied to it this information is stored in episodic memory. As soon as the stimulus is presented again this first encounter, including the rule, is automatically retrieved (Allport & Wylie, 2000; Waszak et al., 2003). Therefore, once a target has become connected to a task rule (by instruction, practice, or chance) the rule is used, not because of the subject's intention or strategy but because of automatic retrieval.

In any case, performance of subjects using task rules differed from performance of subjects basing their responses on SR mappings. Only the former showed switch costs. The latter performed well without being affected by color switches or repetitions. Despite their (in this case) apparent disadvantage, subjects who knew the rules applied them. This indicates that the assumption that subjects actually switch between rules in task switching studies is right. So the question remains: why are rules preferred? This preference would only seem adaptive if it came with a benefit.

DEFINITIONS

Before commencing with studies on the shielding function of task sets and the supposed benefit of rule use, I would like to insert some general comments on the definition of task set and the terminology used in this thesis. One of the core assumptions of the task switching paradigm is that subjects apply two or more tasks. Yet, the terms task or task set evade a straightforward definition. Vandierendonck, Liefooghe, and Verbruggen (2010) argue that the definition of task set ideally includes all parameters that have been shown to affect performance in task switching. They propose that based on empirical evidence, these parameters are "[…] stimulus-category rules, category-response rules, orientation of attention (attentional bias), response threshold, and response modality" (Vandierendonck et al., 2010; p. 612). Of course, future research might unveil additional parameters. Likewise, not all listed parameters are of equal importance in all tasks. For instance, few task switching studies require subjects to shift response modalities (e.g. switch between oral and manual responses). One might say that, in sum, a task set provides a subject with all the information necessary to successfully perform a given task. However, instructions may vary concerning specificity or generalizability. With respect to the present thesis, the distinction between tasks that include categorization rules and tasks based on separate SR mappings (Dreisbach et al., 2007) is crucial. According to some definitions, both would constitute a *task set*. On the other hand, Mayr and Keele (2000, p.5) state that "The critical feature that distinguishes task sets from representations of simple actions and, thus, that makes them representative of 'high-level constraints on action selection' is their abstractness. That is, they contain specifications that are relevant for all possible realizations of a particular task (e.g., 'attend to color') instead of information that would be critical for the implementation of simple actions (e.g., 'red')." Most task switching studies use rules that fit this definition. Subjects are commonly instructed to categorize stimuli according to different rules (e.g. consonant/vowel, odd/even etc.), rather than use a number of single mappings. However, there are exceptions (e.g. Waszak, Wenke, & Brass, 2008).

In their first studies, Dreisbach and colleagues refer to the shielding function of *task sets*. Still, this – theoretically – might include the application of SR mappings according to some definitions. Yet, as will be outlined below, the shielding function is a consequence of using categorization rules rather than arbitrary mappings. Therefore in this thesis, the term *task set* is used to describe task representations in terms of (mostly binary) categorization rules. Alternatively, these will also be referred to as *task rules, categorization rules,* or simply *rules*. Separate, arbitrary mappings will be referred to as *stimulus-response (SR) mappings*. These establish an association between a specific stimulus and a response, without an intervening process of categorization. Although these mappings also constitute a task, the term *task set* as used in this thesis will not include them. In reference to Dreisbach and Haider (2009) conditions in which subjects are instructed to use categorization rule will be referred to as task set (TS) condition or TS group. Subjects instructed to use separate mappings will be referred to as being part of the SR condition or SR group.

First Findings on the Shielding Function

The results from Dreisbach et al. (2007) show that rules are – at least to some degree – preferred over arbitrary mappings. However, this was assessed via *costs* that were caused by the application of rules. Participants who had completed the task using rules were slower on color switch trials (i.e. task switches) than on color repetition trials (i.e. task repetitions). Put differently, participants apparently opted for rule use although it was the less effective and sometimes even the slower approach. Dreisbach and colleagues reasoned that comparing an SR strategy with a switching strategy might not be suited to uncover potential benefits offered by task rules. Apparently, switching back and forth induces a cost but the use of a single rule might lead to superior performance over both switching and applying SR mappings. Based on unpublished results from a previous study, Dreisbach and Haider (2008) already had specific expectations regarding the nature of the advantage of using a single rule. They suggested that the implementation of a task rule helps shield from irrelevant information. That is, the performance of subjects who apply a stable categorization rule rather than arbitrary mappings should not be affected by irrelevant stimulus features. This was the first time the *shielding function of task sets* was proposed. The authors directly compared the use of one vs. two rules with performance based on SR mappings. The experimental setup was similar to that used by Dreisbach et al. (2007) but the late information condition was replaced by a group of subjects applying only one rule. Thus, again, three groups of subjects responded to the same targets with the same response keys. Like in the previous study they differed in the way the task was represented: One group switched between two rules (2TS), one group applied only one rule (1TS), and the third group based their performance on separate SR mappings (SR). The stimuli and mappings that were used are displayed in Table 2.

Table 2*. Stimuli and tasks used in Experiment 1 of the study by Dreisbach and Haider (2008; adapted from Dreisbach & Haider, 2008).Translations are added in parentheses.*

		2 Task Sets				
		Animal	**No animal**	**Consonant**	**Vowel**	
1 Task Set						**Response key**
	Moving	Laus (louse) Iltis (polecat)		Bein (leg) Pendel (pendulum)		**Left**
	Non-moving		Sofa (sofa) Ulm (Ulm)		Anker (anchor) Eis (ice)	**Right**

Dreisbach and Haider looked into sequential interactions between the color of the target stimulus and the response. In the 2TS condition the color was relevant insofar as it was the cue that indicated which task to perform. A color switch indicated a task switch, whereas if the color repeated, so did the task. In contrast, in the 1TS and the SR conditions stimulus color was an irrelevant feature that conveyed no information. Dreisbach and Haider expected to find an interaction between color and response in the 2TS and SR condition. In contrast, the irrelevant feature should not affect performance in the 1TS condition due to the shielding quality of the task set.

The results were as predicted. For subjects in the 2TS and SR conditions, there was a response repetition benefit on color repetitions, whereas on color switch trials response repetitions resulted in a cost. Subjects in the 1TS group showed a small overall response repetition benefit but this was not affected by color changes. This was attributed to the proposed *shielding function of task sets*. Information without relevance to the task was supposedly shielded against. Dreisbach and Haider proposed that in a switching context this shielding function might even contribute to the switch cost because on a switch the previously irrelevant but now relevant information is still shielded from to some degree. Although there were alternative explanations to the results, attributing the lack of an influence of target color to rule use was the most plausible.

The study by Dreisbach and Haider (2008) for the first time directly showed that applying task rules does not only result in the costs that are usually the subject of task switching experiments. Rather, using a rule might be beneficial whenever there is the possibility of distraction. Rules help shield against irrelevant information. Irrelevant, in this case, refers to any stimulus or stimulus attribute that does not provide task-related information. Yet, claiming that shielding is such a global function seemed somewhat premature. After all, evidence for the shielding function was very specific: a lack of binding effects between an irrelevant stimulus dimension and the response. In a follow-up study, Dreisbach and Haider (2009) therefore introduced a different kind of distraction to assess the shielding function of task sets. Instead of looking into binding effects they now used spatial compatibility effects caused by distracters in a word-picture Stroop-like paradigm. Subjects had to respond to eight target words by either using a rule (TS group) or separate SR mappings (SR group). So, again, the critical manipulation was the instruction condition. Target words were articles of clothing. The rule was to decide whether the object covered part of the leg or not. This categorization rule was helpful yet arbitrary enough to prevent participants in the SR group from guessing it.

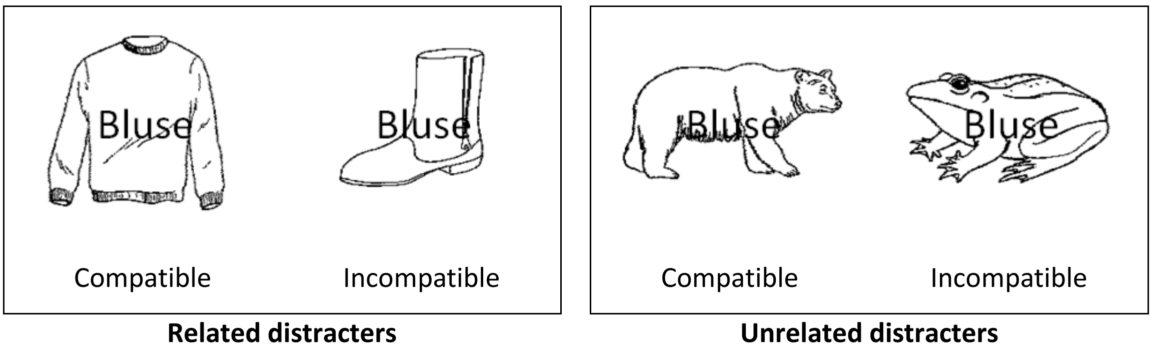

Figure 2. *Compound stimuli used by Dreisbach and Haider (2009). Semantically related distracters are line drawings of objects that also serve as targets (words). Unrelated distracters are spatially oriented animals. In this example, the word “Bluse” (blouse) was associated with the right response key, and the word “Stiefel” (boot) was associated with the left response key (adapted from Dreisbach & Haider, 2009).*

This time, all words were presented in black color but superimposed on distracter pictures. Half of the pictures were semantically related to the words in that they were line drawings that depicted the objects from the target set (related distracters). The other distracters were line drawings of animals looking to the left or to the right (unrelated distracters). Both types of distracters could be compatible or incompatible. For the semantically related pictures compatibility resulted from the mappings given in the instruction. If target and distracter were mapped to the same response the compound stimulus was compatible. If they were mapped to different responses the stimulus was incompatible. Unrelated distracters were compatible if their spatial orientation matched the response, and they were incompatible if the spatial orientation did not match the target response. For instance, if clothes that cover parts of the leg were associated with the right response key, the word '*Bluse'* (*blouse*) superimposed on the picture of a sweater would be compatible, while the same word superimposed on the picture of a boot would be incompatible. Likewise, an animal looking to the right would be compatible with *blouse*, whereas an animal looking to the left would be incompatible (see Figure 2)

Spatial compatibility effects are most typically found when target- and response-features overlap (Simon-effect; e.g. Simon & Rudell, 1967). For instance, if subjects use a left or right response key to respond to a non-spatial feature of a target (e.g. color), presenting the target to the left or the right of fixation results in compatibility effects. Responses are faster when the localizations of target and response match than when they mismatch, although target location is irrelevant to the task. This effect is not only found if the target is actually spatially located. Spatial information can also be conveyed via arrows (Pellicano, Lugli, Baroni, & Nicoletti, 2009) or gaze direction (e.g. Ansorge, 2003). Adapting the Eriksen flanker task (Eriksen & Eriksen, 1974) for children, Rueda et al. (2004) found that even spatially oriented drawings of animals can successfully interfere. In flanker tasks, a centrally presented target is flanked by two identical stimuli which are either response-congruent or incongruent with the target. Responses are slower when target and flankers are mapped to the same response than when they are not. Using colored line drawings of fish looking to the left or to the right, Rueda et al. (2004) found a significant flanker effect. This prompted the idea of Dreisbach and Haider (2009) to use spatially oriented animals as distracters.

The results from this second study on the shielding function were remarkably clear. Instruction condition (SR vs. TS), Compatibility, and Distracter relatedness (related vs. unrelated) interacted significantly. Line drawings that were semantically related to the targets interfered in both groups. Subjects were faster and made fewer errors when target and distracter were mapped to the same response. In addition, line drawings of spatially oriented animals interfered in the SR condition: Subjects using SR mappings were affected by whether response location and the spatial orientation of the distracter matched or mismatched. In contrast, there was no compatibility effect for spatial distracters in the TS condition. The general pattern of these results is displayed in Figure 3. It is typical for task shielding: the SR group is affected by all types of distracters, whereas in the TS group, only distracters with task-related features interfere.

In a second Experiment, Dreisbach and Haider (2009) found that it is not the instruction per se, but rather the eventual task representation that results in shielding. In Experiment 2 all subjects received SR instructions. In contrast to Experiment 1, words were not introduced stepwise but all at once. That way some participants were expected to form their own task rule. In a post-experimental questionnaire subjects were asked how they had memorized the mappings. Based on their answers the between-subjects factor *task representation* was determined post hoc. Subjects who had created their own rule were now part of group TS, whereas subjects who reported having used the separate mappings constituted the SR group. With this procedure, the same general pattern of interference as in Experiment 1 was found. In the SR group compatibility effects were significant for all distracters, whereas in the TS group only semantically related distracters interfered. This was taken as evidence that the shielding function is not a consequence of task instruction but of how subjects eventually represent the task.

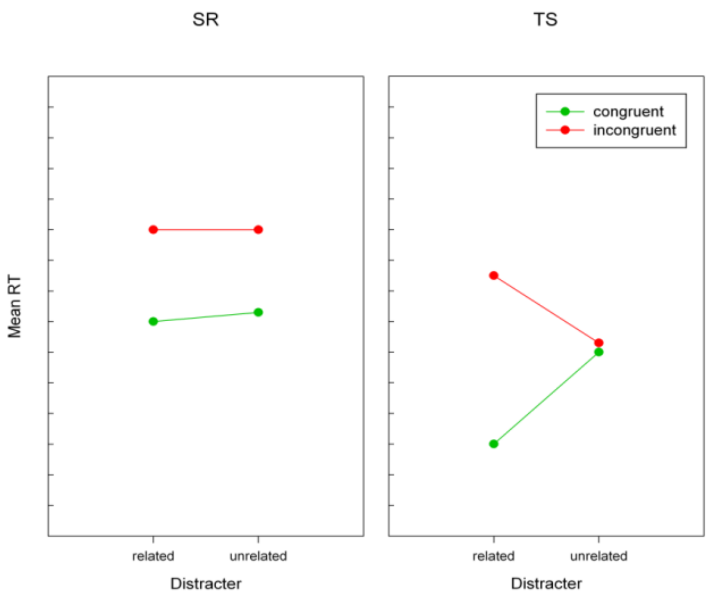

Figure 3. *Typical pattern of interference results displaying the shielding function of task sets (adapted from Dreisbach & Haider, 2009).Related distracters are semantically congruent/incongruent with the target. Unrelated distracters are spatially oriented and thus match/mismatch the response.*

Interestingly, in the SR group the susceptibility to interference by spatial distracters disappeared when subjects practiced the mappings without distracting pictures. Dreisbach and Haider (2009; Experiment 3) found no compatibility effect for the SR group when no line drawings were shown during the introduction of the target words and in a first practice block. This might imply that it is indeed the reduction of information to relevant attributes that makes shielding possible. In her review on the shielding function of task sets Dreisbach (2012) emphasizes that task rules define the features of a target that are important with respect to the response. One could assume that practicing SR mappings without distracters also highlights the important features. When distracters are introduced later they can more easily be discarded as irrelevant.

In the experiments reported so far there is a factor confounded with rule use. Remember that subjects in the TS group had to memorize only two category-response mappings, whereas subjects in the SR group learned eight separate mappings by heart. Lavie, Hirst, De Fockert, and Viding (2004) proposed that perceptual load should decrease the impact of distracting information, whereas high WM load should lead to increased susceptibility to distracters. Perceptual load was identical in both groups since the targets did not differ. However, working memory load was supposedly higher in the SR group. This could account for the difference in interference: load was higher in the SR group, which therefore was more susceptible to interference. However, Dreisbach and Haider state that with low WM load, the TS group should have shown attenuated interference for all distracters. Yet, only interference from spatial distracters was absent.

For the sake of completeness it must be noted that shielding does not prevent interference from spatial information in general. The Simon effect is actually increased in subjects using a categorization rule (Metzker & Dreisbach, 2009, 2011). That is, if the spatial information is not conveyed via separate distracters (like line drawings of animals) but is inherent in the target (i.e. the target is presented at different spatial locations) congruency effects are larger for the TS group than for the SR group. Metzker and Dreisbach explained this effect by proposing a third processing route for the Simon effect (see also General Discussion). This route causes the location of the target to prime the response category associated with that location. More precisely, if subjects are instructed to respond to odd numbers by pressing the left response key, then odd numbers activate the response *left* (controlled route) while at the same time, *left* activates the response category *odd* (third route). That is, if an odd target is presented on the left hand side of the screen, the stimulus category is primed by the position. On the other hand, if it were an even number, the competing stimulus category would be primed by the position, which in turn would negatively affect performance. The effect of this third route on response times supposedly is particularly prominent for the TS group because there are only two response categories. Consequently, each location only (and hence strongly) primes one category. In contrast, with an SR approach each location is associated with four different stimuli rather than one category, resulting in comparatively little priming and hence less influence on the overall Simon effect.

RELAXATION OF THE SHIELDING FUNCTION

So far, results showed that task representations in terms of binary categorization rules help shield against irrelevant information. This shielding function of task sets was found by comparing performance of subjects in a single task condition to that of subjects using arbitrary mappings. Dreisbach and colleagues had abandoned the switching paradigm, in order to find evidence for the beneficial effects of rule use. With this knowledge, in 2011, Dreisbach and Wenke returned to the switching paradigm. The authors for the first time specifically studied the shielding function in a switching context.

Previously, it had already been suggested that the shielding function might contribute to switch costs (Dreisbach & Haider, 2009). The fact that the preceding task is still active to some degree on a task switch, whereas previously ignored information becomes relevant could contribute to the cost associated with switching. So, in order to minimize detrimental effects on task performance shielding should be relaxed on task switches. Otherwise, subjects might tend to persevere and performance would become rigid. This is in line with the assumption that the cognitive system must find a balance between stability and flexibility of behavior (e.g. Goschke, 2003). The shielding function contributes to stable task performance but shielding would impede flexibility if it was not adjustable to changing requirements. In sum, shielding should be adaptive on task repetitions. However, as soon as task demands change (e.g. on a switch trial) shielding should be relaxed. This assumption was tested by Dreisbach and Wenke (2011). The lack of binding effects found in a previous study (Dreisbach & Haider, 2008) was taken as an indication of intact shielding. On the other hand, relaxed shielding was expected to result in the usually observed binding effects between the response and an irrelevant target feature. Subjects had to switch between two categorization tasks: They had to classify digits as odd or even, and letters as being a consonant or a vowel. The stimulus itself indicated the task so that no further cues were needed. Targets were presented with two different irrelevant surface features (Experiment 1: color; Experiment 2: font). This feature varied randomly from trial to trial. 2 (task: repetition vs. switch) X 2 (response: repetition vs. switch) X 2 (irrelevant feature: repetition vs. switch) analyses of variance revealed that indeed, on task repetitions the interaction between response and feature was non-significant. Thus, results from the study by Dreisbach and Haider (2008) were replicated. With shielding being intact irrelevant feature changes did not affect performance. In contrast, on task switches response and color (Experiment 1) or font (Experiment 2) interacted. The response switch benefit that is usually observed on task switches (e.g. Hübner & Druey, 2006; Kleinsorge, 1999; Rogers & Monsell, 1995) was present for feature repetitions but not for switches. In sum, the irrelevant color or font of the target affected performance on task switches but not on task repetitions. The authors interpreted this result in terms of intact shielding on task repetitions, and a relaxation of the shielding function on task switches. For this interpretation the exact nature of the interaction on task switches is extraneous. Only the fact that the irrelevant feature affected response repetitions and switches differentially is important with respect to the proposed relaxation of shielding. Still, Dreisbach and Wenke offered an explanation for their results: A learning mechanism was most suited to account for the specific findings on switch trials. According to this account, responding to a target strengthens the association between the given stimulus category and the response at the cost of the competing category associated with that response. On task repetitions, a response repetition results in a benefit because the now strongly associated category and response are repeated. In contrast, on a task switch, a response repetition would result from the presentation of a target from the weakly associated category. This would result in the observed cost (or lack of benefit) for task repetitions. As for the irrelevant feature: a repetition of the feature would not interrupt and might even increase this effect. However, a feature change – although irrelevant – might loosen the strong association between the previous category and response, thereby eliminating or even reversing response repetition costs on task switches (Spapé & Hommel, 2008).

SCOPE OF THE PRESENT WORK

The results of the four studies on the benefits of rule use can be summarized as follows:

- Subjects prefer the use of categorization rules over learning separate SR mappings. Even if separate mappings have already been practiced or are implicitly suggested by the experimental setup, rules are applied when they are known. This preference is indexed by the presence of switch costs (Dreisbach et al., 2007).
- Comparing performance of subjects using a single rule with that of subjects using separate SR mappings reveals a potential benefit of rule use. Subjects using an SR strategy show binding effects between an irrelevant stimulus feature and the response. This binding effect is not found in the TS group. Apparently, task rules help shield against this irrelevant information (Dreisbach & Haider, 2008).
- The shielding function is not restricted to binding effects but is also found with irrelevant spatial distracters. When target words are superimposed on pictures of spatially oriented animals a compatibility effect is found for subjects using SR mappings but not for subjects using a categorization rule (Dreisbach & Haider, 2009).
- Shielding is only adaptive on task repetitions. As soon as task demands change, for instance on a task switch, the shielding function is relaxed. This relaxation is evidenced by binding effects on task switches (Dreisbach & Wenke, 2011). It prevents perseveration but at the same time might increase distractibility on task switches.

In sum, the shielding function seems to be a global control function that results from representing a task as a binary categorization rule. It is global in the sense that – as long as the task does not change – it does not vary from trial to trial, and applies to more than one kind of distraction unrelated to the task. It must be noted that the shielding function need not necessarily be an independent mechanism. It might be a simple byproduct of task representation. In any case, the robust effects of task representation on distractibility are worth a closer look. Although shielding has now repeatedly been found it is still not clear what processes underlie the function. In early studies, Dreisbach and colleague proposed that it might be attentional bias (Dreisbach & Haider, 2008, 2009). Yet, more recent results suggest that the distracting information is processed but might be prevented from entering the response system (Dreisbach & Wenke, 2011). The aim of the present thesis was to further investigate the shielding function of task sets and shed some light on its causes and effects.

The first set of studies addressed the question, whether shielding is found with distracters that are related to the instruction. Dreisbach and Haider showed that completely irrelevant information such as spatially oriented animals or target color was shielded against, whereas related information interfered. However, *related* distracters were a very specific type of task-related in that they were pictorial equivalents of target words and as such part of the instruction. Therefore, interference might have arisen for more than one possible reason, such as retrieval of event files (Hommel et al., 2001) or an instruction-induced bias. Yet, from an economical point of view it is reasonable to assume that any information with task-related features would not be shielded against. If shielding is a result of categorical task representation it seems likely that information matching the relevant categories would be processed because it most probably is relevant. In contrast, information not pertaining to those categories should be shielded against. This hypothesis was tested in a first set of studies in a setup similar to that of Dreisbach and Haider (2009). I expected distracter pictures that were related to the task (i.e. could be categorized according to the rule) to interfere even if they were not pictorial equivalents of the distracter words. Interference from such task-related distracters implies that the shielding function is supported by preferred processing of task-related material rather than distracter inhibition. This implication was tested more directly in the second set of studies.

In Part III of the present thesis the shielding function was studied in a switching context. Dreisbach and Wenke (2011) already showed that shielding is reduced on a task switch. This reduction was now used to further assess whether shielding is an inhibitory function or whether it relies on preferred processing of task-related information. Subjects switched between two word categorization tasks meanwhile ignoring distracting pictures that were either related to one of the tasks or spatially oriented. Interference by these pictures on switch trials (i.e. when shielding supposedly was reduced) should help decide whether shielding reflects inhibition of distracters or preferred processing of task-related information. More specifically, r*educed inhibition* and *reduced preferential processing* make different predictions regarding interference by task-related and spatial distracters on random switch trials: Reduced inhibition would amount to increased interference on switch trials, whereas a reduction of preferential processing should result in attenuated interference by task-related distracters.

The last experiment of the present thesis was a follow-up study on Part III, which suggested that task activation is an important factor concerning the effectiveness of shielding. This was tested directly by employing the alternating runs paradigm rather than the unpredictable task switches used in Part III. The predictability of task order was expected to allow subjects to prepare the upcoming task. This preparation should have a beneficial effect on task activation. If shielding is indeed related to task activation this should show in the pattern of interference on task switches. In contrast to results from random task switching shielding should now not be reduced because advance preparation enables stronger task activation.

PART II

THE SHIELDING FUNCTION OF TASK SETS IN THE PRESENCE OF TASK-RELATED DISTRACTERS

INTRODUCTION

One of the hallmarks of human cognition is our ability to react in accordance with any instruction sometimes even without prior practice. Thereby, we are often able to ignore distracting information and concentrate on the task at hand. The shielding function of task sets helps us focus on relevant aspects of the task, basically preventing interference from irrelevant information. But what if the distracting information is related to the task? Does the shielding function still prevent interference? Imagine – on the day before your little garden party – going grocery shopping. You would have no problem shopping for *limes*, *mint*, and *soda* by the rule *Things I need for a cocktail* if you intended to serve Mojitos the next day. When using this rule, shielding would presumably prevent other information such as cheese being on sale from interfering with your shopping. But what about groceries that fit the category, yet are not needed? For instance, you might have rum at home so there would be no need to buy any. However, *rum* fits the category *things you need for a cocktail*. How would the shielding function offered by rule use affect such a distracter? Would you briefly consider buying rum, maybe rethinking whether you really have enough at home? Or would you strictly stick to the cocktail-items on your list, ignore the rum, and not be affected if you saw it next to the check-out counter or in the cart in front of you? It seems likely that shielding would not keep you from distraction in such a case and that seeing the rum would affect you, at least for a short time. Consider this: the shielding function of task sets prevents interference by irrelevant information. But how does the system know which information is relevant and which is not? It would be sensible and economical that the instructions define response relevance. In the case of categorization rules the instructions provide two (or possibly more) permitted alternatives. Therefore, anything not matching these would be shielded against (e.g. cheese, not a cocktail ingredient). However, this would not apply to distraction that falls within the categories deemed relevant by the instruction (in this case *things you need for a cocktail*). The main question addressed in this set of studies is whether or not the shielding function of task sets prevents interference by task-related distracters in such a case. One possibility is that shielding is inhibitory and very selective, applying even to task-related information in an interference-preventing manner and failing only in the presence of stimulus-specific interference (i.e. related distracters in the study by Dreisbach & Haider, 2009). Only the shopping items on your list would affect your shopping behavior whereas related ingredients like the rum you already own would be ignored. Alternatively, the shielding function might reflect sensitivity to features deemed relevant by the instruction. Stimuli fitting this criterion would be categorized according to the rule. Although you do not need the rum, seeing it might distract you for a moment until you realize that there is no need to buy it. Note that in this case the presence of interference would not indicate a lack of shielding. Rather, the shielding function of task sets would affect irrelevant (cheese) and related (rum) distraction in different ways. Interference from irrelevant information is prevented, whereas interference from related distracters might actually be promoted.

As already mentioned above, it seems reasonable to assume that potentially relevant information is processed irrespective of whether it is part of a target or a distracter. I therefore hypothesized that shielding does not prevent interference from distracters that are related to the task by category. Instead, like the distracters corresponding to the target words in the study by Dreisbach and Haider (2009) they should result in a congruency effect caused by categorization according to the rule. In the present experiments distracters corresponding to Dreisbach and Haider's *related* distracters will be referred to as *target-related* because they depict the objects that also serve as target words. The newly introduced distracters that can be categorized according to the task rule but are otherwise not related to the targets will be referred to as *task-related* distracters. In sum, the rule can be applied to both target-related and task-related distracters but only target-related distracters correspond to the actual targets words.

There is already evidence that instructions might be sufficient to evoke a response, indicating that rules might automatically be applied and shielding should not be expected. For instance, the idea of the *prepared reflex* (Woodworth, 1938; see also Hommel, 2000, for a more timely review of this metaphor) suggests that the mere instruction of a simple SR mapping is sufficient for automatic response activation once the target is encountered. Cohen-Kdoshay and Meiran (2007, 2009) were the first to provide unequivocal evidence for this idea of a prepared reflex by carefully excluding alternative interpretations. They showed that flanker interference already occurred in the very first trial following the instruction without any prior practice, indicating automatic response activation. Note that the authors specifically ruled out retrieval of response codes from LTM as an alternative explanation, since in the very first trial the task had never been executed before. Wenke, Gaschler, and Nattkemper (2007) also found evidence for instruction-based response activation. They developed a dual task paradigm in which arbitrary and new SR instructions given for task A influenced performance in a subsequent task B even if task A had not been executed yet. The authors concluded that binding between stimulus and response features can occur by mere instruction without actual response execution. Taken together these studies provide clear evidence for instruction-based response interference suggesting that task-related distracters might indeed interfere. However and importantly, so far results are limited to instances of stimuli that were introduced as potential targets at the beginning of the experiment. In contrast, here I investigated whether the same holds true for stimuli that are never introduced as targets. That is, is a task rule—once instructed—automatically applied to distracter stimuli even if they never served or will serve as target stimuli? Or does the shielding function prevent such interference? Findings from the task switching literature already suggest that task rules can automatically be activated as indicated by the TRCE. Unlike the prepared reflex, the TRCE is not affected by WM load (Kessler & Meiran, 2010; Kiesel et al., 2007; Meiran & Kessler, 2008), and it is not limited to stimuli that are presented in both tasks. A study by Kiesel et al. (2007) showed that the use of a task rule resulted in a TRCE even for targets that were uniquely presented in one of the two tasks. Similarly, Yehene, Meiran, and Soroker (2005) found a TRCE for subjects who expected to switch between tasks but in fact only performed one task throughout the experiment. Results from both studies indicate the possibility of automatic application of an instructed rule. However, in both studies instructions related to different features of the same set of stimuli (magnitude vs. parity and size vs. shape of an object, respectively). Accordingly, interference arose not from an irrelevant stimulus (i.e. a separate distracter), but from the currently irrelevant feature of an otherwise relevant stimulus (the target). Moreover, interference was caused by a currently *irrelevant* rule. In contrast, in this study I chose a paradigm that more or less excludes the possibility of stimulus-specific retrieval to provide more unequivocal evidence that a currently *relevant* task rule is automatically applied to irrelevant distracters and shielding therefore does not prevent interference by task-related distracters. To the best of my knowledge, the only evidence for the automatic application of task rules to non-target stimuli comes from priming studies. Congruency effects between primes and probes are found even if the stimuli used as primes never served as targets and hence were never consciously perceived or responded to (e.g. Klauer, Eder, Greenwald, & Abra ms, 2007; Naccache & Dehaene, 2001; Reynvoet, Gevers, & Caessens, 2005; van den Bussche, Notebaert, & Reynvoet, 2009; Van Opstal, de Lange, & Dehaene, 2011; van Opstal, Gevers, Osman, & Verguts, 2010). Yet, these studies are not designed to examine the automaticity of rule application or specificity of shielding, but rather the depth of processing of subliminally presented stimuli. Here, I aim to extend these findings to consciously perceivable distracters that are shown simultaneously with a target in order to assess whether these are shielded against. In addition, in three of the experiments instead of using natural categories (e.g., odd/even) or separate, independent SR mappings, I employed a novel categorization rule that (a) can be applied and generalized to a large range of stimuli (b) encompasses stimuli that are otherwise not semantically related (i.e. are from different natural categories such animals, food, furniture, plants etc.), and (c) is not likely to be over-learned or practiced often in everyday life.

Summing up, there is evidence that instruction of SR mappings is sufficient to cause response interference. So far the evidence is limited to specific, arbitrary SR mappings and does not extend to newly introduced categorization rules. Yet, studies on the TRCE and priming studies suggest that (natural) categorization rules can indeed be applied automatically. Here, I investigated whether novel categorization rules result in the automatic categorization of distracters, which would thereby lead to interference despite shielding. This was done by looking into congruency effects (see Dreisbach & Haider, 2009). I hypothesized that shielding does not prevent interference from task-related distracters. Consequently, congruency effects should occur for both, target-related as well as task-related distracters. The former would replicate findings by Dreisbach and Haider (2009), whereas the latter would show that information deemed relevant by the instruction is automatically categorized.

EXPERIMENT 1

The first experiment served as a pilot study. A simple number categorization rule was used to investigate whether distracters that were never presented as targets (and therefore never associated with a response via instruction or practice) would interfere with target processing. Participants had to make parity judgments on number words by pressing a right or left response key. The number words were superimposed on Arabic numerals. Half of the numerals depicted numbers that were part of the stimulus set (see Introduction). The other half consisted of numerals that were not part of the stimulus set but – like all numbers – could be categorized as being odd or even (task-related distracters). At the beginning of the experiment participants were informed which target words would appear and were asked to ignore the distracter numerals. If the shielding function prevents interference from task-related information a congruency effect would be expected only for target-related distracters. In contrast, if shielding works differently on information related to the instructed task (as compared to completely irrelevant information), both target-related and task-related distracter numerals should result in congruency effects. At the same time, such a result would provide first empirical evidence for the automatic application of rules to irrelevant distracter pictures.

METHOD

PARTICIPANTS

12 students from the University of Regensburg (7 women, mean age = 24 years, age range: 19-45 years) participated for partial course credit. All had normal or corrected to normal vision. Participants signed informed consent and were debriefed after the session.

APPARATUS AND STIMULI

Number words from *one* to *nine* excluding *five* served as target stimuli. Participants' task was to decide whether the number word was odd or even by pressing a left or right response key, respectively. The target stimuli were superimposed on Arabic numerals which always served as distracters. Such compound stimuli were either congruent (both, target and distracter were odd/even) or incongruent (the parity of target and distracter did not match; see Figure 4). In order to disentangle stimulus-specific from task-specific interference only half of the number words could appear as targets for a given group, whereas distracter numerals were always drawn from the entire stimulus set. More precisely, target stimuli were split into two sets of four number words each (Set A: one, two, eight, and nine; Set B: three, four, six, and seven). Subjects were randomly assigned Set A or Set B. Numerals from both sets served as distracters. In sum, using four number words and eight distracters per group, there were a total of 32 possible word-numeral compound stimuli. Half of them were congruent, the other half were incongruent. Half of the distracters were target-related (i.e., also shown as targets), the other half were task-related (never shown as targets but still odd/even).

This and all the following experiments were programmed in E-Prime (Psychology Software Tools, Pittsburgh, PA). Subjects were seated in front of a monitor at a viewing distance of approximately 50 cm. Word-numeral compound stimuli appeared in the center of the screen, presented against a white background. Words were presented in size 18 Arial font and purple color, in order to make them easier to read in front of the black and white distracters. Responses were registered on a standard QWERTZ keyboard. Even numbers were mapped to a right response key ('-'-key), odd numbers were mapped to a left response key ('y'-key). This mapping was used because an advantage for the even-right/odd-left mapping over the odd-right/even-left mapping has been reported repeatedly (linguistic markedness association of response codes [MARC] effect; Cho & Proctor, 2007; Nuerk, Iversen, & Willmes, 2004)).

Figure 4. *Examples for the compound stimuli from Experiment 1. The compound stimuli are illustrative and do not match the actual stimuli exactly in size and position.*

PROCEDURE

Each trial started with a fixation cross for 400 ms followed by a blank screen for 400 ms. Then the imperative stimulus (word-numeral compound stimulus) appeared and stayed on the screen until a response was made. The ITI was 400 ms. In case of an error a red cross appeared for 1600 ms, prolonging the ITI to 2000 ms (see Figure 5). The experiment started with written instructions on the computer screen. Subjects were instructed to make parity judgments on the words only. Both accuracy and speed were stressed. In a short practice block of eight trials all number words from the relevant set were presented two times each in random order without distracters. After this short practice block four experimental blocks followed. Each block consisted of 64 trials (all 32 possible target-distracter compounds presented twice). Participants started each block by pressing the space bar. Trials were presented in pseudo-random order with word repetitions, distracter repetitions and negative priming trials (trials in which the current word matched the distracter presented in the previous trials) not being allowed.

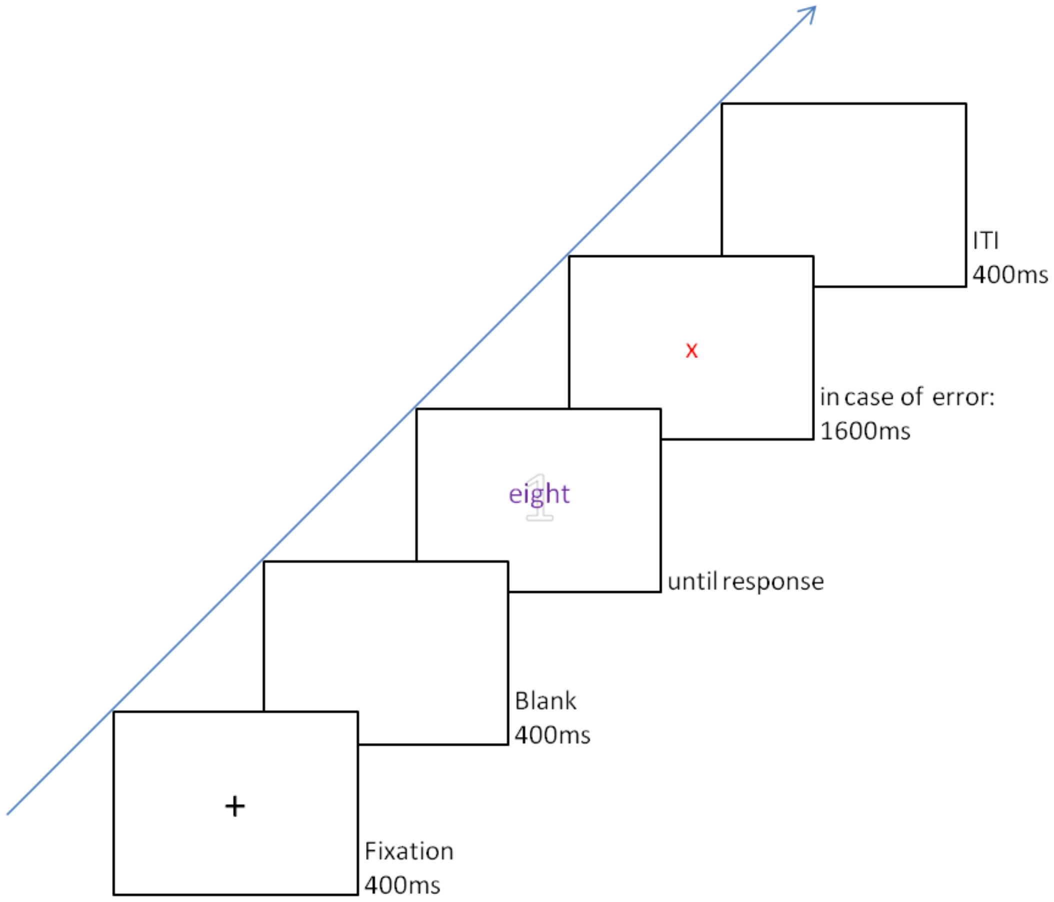

Figure 5. *Trial procedure in Experiment 1.*

DESIGN

A 2 (Distracter: target-related vs. task-related) X 2 (Congruency: congruent vs. incongruent) repeated measures design was used.

RESULTS

In the following four experiments, the same preprocessing procedure was applied: Only the experimental blocks were analyzed. Trials in which target and distracter were identical (Experiment 1: 12.5 %, Experiment 3: 6.7 %; in Experiments 2 and 4 there were no such trials) were excluded from all analyses. Moreover, error trials and trials following an error were excluded from RT analysis (Experiment 1: 7.6 %, Experiment 2: 10.7 %, Experiment 3: 11.8 %, Experiment 4: 10.4 %). Post-error trials were removed to avoid noise due to post-error slowing (e.g. Jentzsch & Dudschig, 2009). To correct for outliers, RTs exceeding two standard deviations from the individual cell mean were also excluded from RT analysis (Experiment 1: 4.8 %, Experiment 2: 5.5 %, Experiment 3: 4.4 %, Experiment 4: 1.9 %). A significance level of .05 was adopted for all analyses. For significant effects, individual *p*-values will not be reported in the text.

RT DATA

Individual cell means were entered into a 2 (Distracter: target-related vs. task-related) X 2 (Congruency: congruent vs. incongruent) analysis of variance (ANOVA) with repeated measures. The results are displayed in Figure 6 (see also Table 3). The main effect of Congruency was significant, $F\,(1,11) = 34.74$, $\eta^2 = .76$. Congruent trials were answered faster than incongruent trials (583 ms vs. 605 ms). Distracter did not prove reliable, $F < 1$, $p = .86$, but interacted significantly with Congruency, $F\,(1,11) = 7.29$, $\eta^2 = .40$. Planned comparisons revealed significant congruency effects for both target-related distracters, $t(11) = 7.96$, and task-related distracters, $t(11) = 2.30$, with the effect being stronger for target-related than for task-related distracters (31 ms vs. 14 ms).

***Table 3**. Results from the main ANOVA conducted in Experiment 1. Significant results (p ≤ .05) are printed in bold.*

	RT (ms)			Error rates (%)		
Effect	**F**	**p**	**η^2**	**F**	**p**	**η^2**
Distracter	< 1	.86	.00	**8.00**	**.02**	**.42**
Congruency	**34.74**	**< .001**	**.76**	**7.08**	**.02**	**.39**
Distracter X Congruency	**7.29**	**.02**	**.40**	1.02	.34	.09

In order to determine whether congruency effects were significant from the beginning or only appeared as a consequence of extensive rule practice later on in the experiment, I ran a separate analysis on Block 1. A 2 (Distracter) X 2 (Congruency) ANOVA resulted in a main effect of Congruency, $F\,(1{,}11) = 11.80$, $\eta^2 = .52$. Responses were faster in congruent trials than in incongruent trials (618 ms vs. 648 ms). The main effect Distracter, $F < 1$, $p = .98$, and the interaction Distracter X Congruency, $F < 1$, $p = .34$, were non-significant.

ERROR RATES

Error data are also depicted in Figure 6 (see also Table 3). A 2 (Distracter: target-related vs. task-related) X 2 (Congruency: congruent vs. incongruent) repeated measures ANOVA revealed significant main effects of Distracter, $F\,(1{,}11) = 8.0$, $\eta^2 = .42$, and Congruency, $F\,(1{,}11) = 7.08$, $\eta^2 = .39$. Participants made more errors in trials with target-related distracters than in trials with task-related distracters (3.8 % vs. 2.3 %), and were more error prone in incongruent than congruent trials (4.2 % vs. 2.0 %). The interaction Distracter X Congruency was not significant, $F = 1.02$, $p = .34$.

An additional analysis on block 1 revealed no significant main effect or interaction, all $F < 2.8$, all $p > .12$.

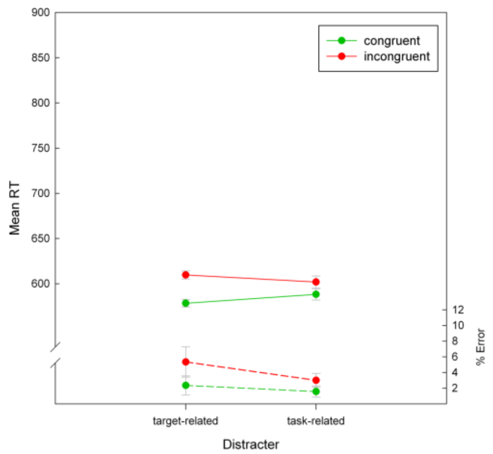

Figure 6. *Mean response times (RTs) in ms and error rates in % as a function of Distracter and Congruency in Experiment 1. Error bars represent inferential confidence intervals (Tryon, 2001) based on comparisons of congruent and incongruent trials.*

DISCUSSION

In line with the hypothesis, Experiment 1 brought up significant congruency effects for target-related distracters and distracters that never occurred as targets. Although subjects used a categorization rule, shielding did not have the interference-preventing effect is has on unrelated information. Instead, congruence/incongruence with the target word always affected response times.

It seems reasonable to assume that task-related distracters were categorized according to the rule because they matched the relevant categories. After all, for such task-related distracters SR associations can be excluded as the source of interference because these distracters were never presented as possible targets in the instruction nor were they practiced. Yet, the fact that odd/even is a natural and familiar categorization for numbers offers a possible alternative explanation. One might argue that task-related distracters were incidentally incorporated into the relevant stimulus set by semantic generalization. For example, in their *action trigger hypothesis*, Kunde, Kiesel, and Hoffmann (2003) propose that the impact of subliminal stimuli is determined by pre-stimulus intentions. Action trigger conditions are specified before the task is carried out and if a stimulus matches these action triggers it evokes a response. In the case of the present experiment this would imply that the numbers that were not presented as targets still could have been incorporated into the trigger set, thereby making interference stimulus-specific after all. Task-related distracters would match the action triggers and lead to activation of their respective responses without ever being targets themselves. However, first, the action trigger hypothesis refers to subliminally presented stimuli, not to distracters presented simultaneously with the target. And second, in the study by Kunde et al. (2003) incidental inclusion of numerals in the action trigger set was contingent on their being enclosed by the targets. More precisely, if the target numbers were 1, 4, 6, and 9, then the remaining numbers 2, 3, 7, and 8 could be incidentally incorporated. On the other hand, if the target range was narrow, for instance if it comprised the numbers 3, 4, 6, and 7, prime numbers outside of this range (i.e., 1, 2, 8, and 9) did not interfere. Consequently, the action trigger hypothesis would have predicted an effect of the factor Stimulus Set in our data: Half of the subjects in our experiment responded to the numbers 3, 4, 6, and 7 in which case the action trigger hypothesis would predict no congruency effect for the distracter numbers 1, 2, 8 and 9. Contrary to this prediction an additional analysis revealed no significant interaction between Stimulus Set and Congruency (RT: $F < 1$, $p = .51$; error rates: $F = 1.23$, $p = .29$). However, given that odd and even numbers from 1 to 9 represent a natural category of very limited range the instruction alone might have sufficed to create bindings between all possible stimuli and their respective responses (see e.g. Wenke et al., 2007). This gives rise to the possibility that the results are not due to automatic categorization but to mere stimulus-specific interference due to SR associations after all. Experiment 2 was conducted to rule out this possibility.

EXPERIMENT 2

In order to provide more unequivocal evidence for automatic rule application and the resulting interference by task-related distracters, in Experiment 2 an unfamiliar categorization rule was used instead of the odd/even judgment on numerals. Participants had to decide whether a word represented a moving or a non-moving object. The novelty of these categories should make advance SR bindings due to action trigger conditions or semantic generalization improbable. This should rule out the possibility that shielding merely did not prevent congruency effects in the presence of stimulus-specific interference. A replication of the results of Experiment 1 would corroborate the finding that shielding does not result in reduced interference from task-related information because the rule is automatically applied to distracters. In order to additionally control for any stimulus-specific effects I now introduced a second group of subjects. Participants in this group did not receive the categorization rule but instead learned all SR mappings by heart (see also Dreisbach & Haider, 2008, 2009). I expected to find congruency effects for both target-related and task-related distracters only in the group that received the categorization rule (TS [task set] group hereafter). In contrast, for the group that simply learned the SR mappings by heart (SR group hereafter) the congruency effect should only be present for target-related distracters. Such a data pattern would provide more compelling evidence for the involvement of task-specific interference effects with task-related distraction.

METHOD

PARTICIPANTS

40 students from the University of Regensburg (34 women, mean age = 22 years, age range: 19-32 years) participated for partial course credit. All had normal or corrected to normal vision and were German native speakers. Participants signed informed consent and were debriefed after the session.

APPARATUS AND STIMULI

16 German words (swing, koala, tractor, spinning top, flag, scales, leg, tramcar, stool, cheese, chest, cactus, bottle, bet, vest, and mountain) and 16 picture stimuli depicting the same objects (Cycowicz, Friedman, Rothstein, & Snodgrass, 1997; Snodgrass & Vanderwart, 1980) were used. Words were presented in size 18 bold Arial font and purple color, in order to make them easier to read in front of the black and white line-drawings (see Figure 7). These compound stimuli appeared in the center of the screen against a white background. Words always served as targets and pictures always served as distracters. In the TS group, the task was to decide whether the word represented a

moving or a non-moving object. In the SR group, participants had to learn the assignments by heart. Only half of the words actually appeared as target words in a given sub-group. That is, the 16 target stimuli were split in two sets of eight words containing four moving and four non-moving objects each. In both sets, the moving and non-moving object words were matched for length and initial letter of the German word. Half of the subjects responded to the words of Set A (swing, koala, tractor, spinning top, stool, cheese, chest, and cactus), the other half received stimulus set B (flag, tramcar, scales, leg, bottle, belt, vest, and mountain). Target stimuli were superimposed on pictures of the corresponding set (target-related distracters) or pictures corresponding to the set of words *not* in use (task-related distracters). With 8 words and 16 pictures there were a total of 128 possible word-picture combinations for each stimulus subset. Only 120 of these possible combinations were presented in the experiment. The eight compound stimuli consisting of identical target and distracter stimuli (e.g. the word *flag* presented on the picture of a flag) were not used.

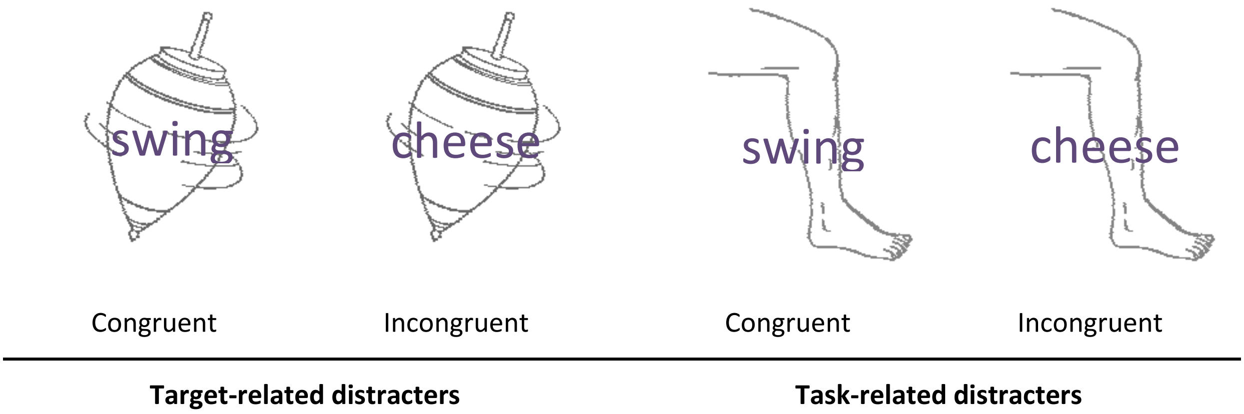

Figure 7. *Examples for compound stimuli used in Experiment 2. In this case, the words swing, cheese, and spinning top are from set A, whereas leg is from set B. The compound stimuli are illustrative and do not match the stimuli used in the experiment exactly in size and position.*

PROCEDURE

Each trial started with a fixation cross for 500 ms followed by a blank screen for 500 ms. Then the imperative stimulus (word-picture compound stimulus) appeared and stayed on the screen until a response was given. A 500 ms feedback was given on every trial: Correct responses were followed by a green fixation cross, a red fixation cross indicated an error (see Figure 8).

Participants were assigned to the SR and the TS group according to their position of entry in the experiment. Subjects read that we were interested in how fast they assigned words to specific response keys (SR condition) or categories (TS condition). They were asked to respond to the words only by pressing the left or right response key. Both speed and accuracy were stressed. Words were then introduced stepwise two per block until in block 4 all eight word stimuli were presented. This stepwise introduction was chosen in order to prevent participants in the SR condition from generating their own task rule (see Dreisbach & Haider, 2009). The introduction of new words was always accompanied by three practice trials per word without a distracter followed by seven compound stimuli with target-related distracters. Additionally, in each of these practice blocks the words that had already been introduced were presented again four times as a compound stimulus with a target-related picture. This procedure resulted in four practice blocks consisting of 20, 28, 36, and 44 trials, respectively.

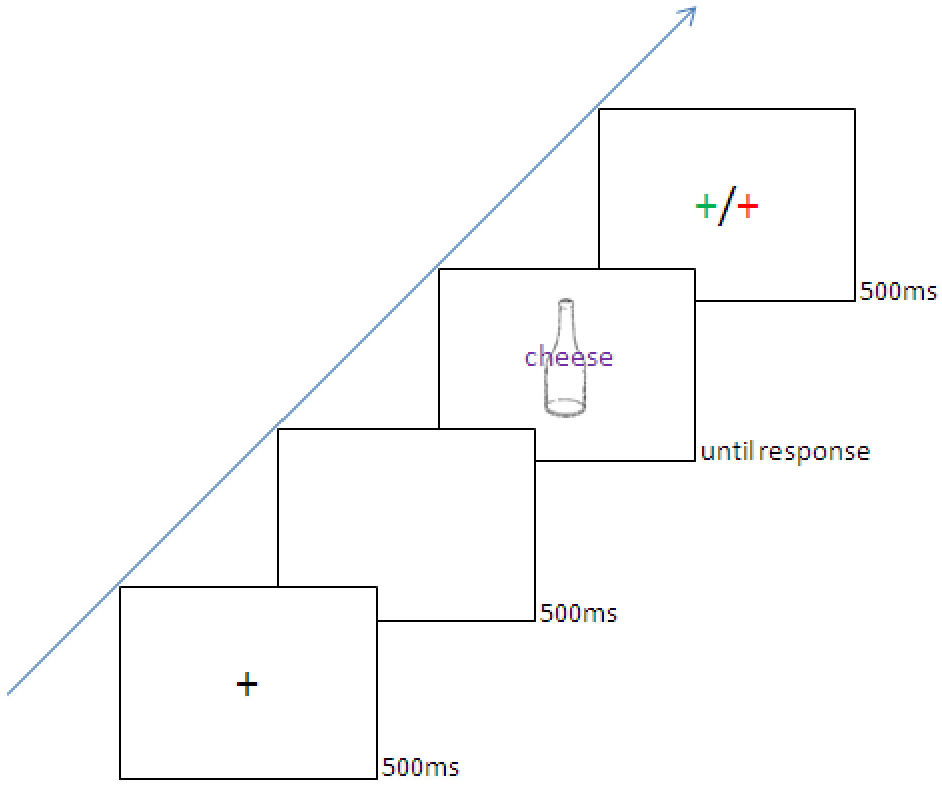

Figure 8. *Trial procedure in Experiment 2.*

After the practice blocks three experimental blocks of 120 trials followed, including 56 trials with target-related pictures (8 words X 7 pictures; identical target-distracter stimuli were not presented) and 64 trials with task-related pictures (8 words X 8 pictures). 56 trials per block consisted of congruent compound stimuli (both word and picture depicted moving objects, or both depicted non-moving objects). The remaining stimuli were incongruent compound stimuli (moving object word and non-moving object picture, or non-moving object word and moving object picture). In a post-experimental interview, participants in the SR condition were asked whether and – if yes – what kind of rule or strategy they had used to memorize the SR mappings. Participants in the TS condition were asked whether they had found the task rule useful, or whether they had used an alternative rule or strategy.

DESIGN

A 2 (Instruction: SR vs. TS) X 2 (Distracter: target-related vs. task-related) X 2 (Congruency: congruent vs. incongruent) design with the within-subjects factors Distracter and Congruency was used. Instruction was manipulated between participants.

RESULTS

None of the participants in the SR condition guessed the underlying task set or generated their own rule. Participants in the TS group all found the rule useful. Thus, all subjects were included in the analysis. The preprocessing procedure was the same as in Experiment 1. In addition, word repetition trials, picture repetition trials, and negative priming trials (the word in the current trial matches the picture in the preceding trial) were excluded from the analysis (*M* = 29.8 % per participant). Results are reported for the three experimental blocks.

RT DATA

An ANOVA involving the between-subjects factor Instruction (SR vs. TS), and the within-subjects factors Block (1-3), Distracter (target-related vs. task-related), and Congruency (congruent vs. incongruent) was conducted (see Table 4).

The main effects of Block, $F(2,76) = 19.16$, $\eta_p^2 = .34$ and Congruency, $F(1,38) = 14.78$, $\eta_p^2 = .28$ were significant. Congruent trials were answered faster than incongruent trials (760 ms vs. 884s). The linear trend of Block was significant $F(1,38) = 32.31$, $\eta_p^2 = .46$. RTs declined with increasing block number (806 ms vs. 768 ms vs. 743 ms). Block interacted significantly with Instruction, $F(2,76) = 7.52$, $\eta_p^2 = .17$. The practice benefit was greater for subjects in the SR group than for subjects in the TS group (SR: 867 ms vs. 811 ms vs. 764 ms; TS: 744 ms vs. 725 ms vs. 721 ms). There was a marginally significant interaction Block X Congruency, $F(2,76) = 2.82$, $\eta_p^2 = .07$, indicating that the congruency effect was largest in block 1, and smallest in block 2 (block 1: 45 ms, block 2: 10 ms, block 3: 21 ms). Most important, Distracter interacted significantly with Congruency, $F(1,38) = 12.88$, $\eta_p^2 = .25$, and this result was qualified by the predicted higher order interaction Instruction X Distracter X Congruency, $F(1,38) = 5.05$, $\eta_p^2 = .11$. This higher order interaction is depicted in Figure 9: The main effect Congruency was significant in the TS group, $F(1,19) = 24.64$, $\eta_p^2 = .57$, but not in the SR group, $F(1,19) = 3.20$, $p = .09$. Distracter and Congruency interacted significantly in the SR group, $F(1,19) = 12.34$, $\eta_p^2 = .41$, but not in the TS group, $F = 1.32$, $p = 27$. No other effects reached significance, all $F < 2.3$, all $p > .1$.

ERROR RATES

Error data are also depicted in Figure 9 (see also Table 4). An ANOVA including Block (1-3), Instruction (SR vs. TS), Distracter (target-related vs. task-related) and Congruency (congruent vs. incongruent) revealed a significant main effect of Congruency, $F(1,38) = 10.19$, $\eta_p^2 = .21$. Errors were more frequent in incongruent trials than in congruent trials (6.4 % vs. 4.9 %). Also, Congruency interacted significantly with Distracter, $F(1,38) = 5.24$, $\eta_p^2 = .12$. The difference between error rates in congruent trials and incongruent trials was greater for target-related distracters than for task-related distracters (2.3 % vs. 0.8 %).

Table 4. *Results from the main ANOVA conducted in Experiment 2. Significant results (p ≤ .05) are printed in bold.*

	RT (ms)			Error rates (%)		
Effect	**F**	**p**	**η^2**	**F**	**p**	**η^2**
Instruction	**3.33**	**< .001**	**.08**	2.61	.12	.06
Block	**19.16**	**< .001**	**.34**	2.64	.09	.06
Distracter	1.52	.23	.04	< 1	.97	.00
Congruency	**14.78**	**< .001**	**.28**	**10.19**	**< .01**	**.21**
Block X Instruction	**7.52**	**< .01**	**.17**	1.36	.26	.04
Distracter X Instruction	1.09	.30	.03	3.04	.09	.07
Congruency X Instruction	< 1	.52	.01	2.50	.12	.06
Block X Distracter	< 1	.40	.02	1.02	.37	.03
Block X Distracter X Instruction	< 1	.91	.00	1.39	.26	.04
Block X Congruency	2.82	.07	.07	< 1	.96	.00
Block X Congruency X Instruction	< 1	.69	.01	< 1	.44	.02
Distracter X Congruency	**12.88**	**< .01**	**.25**	**5.24**	**.03**	**.12**
Distracter X Congruency X Instruction	**5.05**	**.03**	**.12**	1.86	.18	.05
Block X Distracter X Congruency	2.26	.11	.06	< 1	.69	.01
Block X Distracter X Congruency X Instruction	1.31	.28	.03	< 1	.55	.02

DISCUSSION

The results obtained in Experiment 2 again support the hypothesis that shielding does not prevent interference from task-related information but that task rules result in automatic categorization. Target-related and task-related distracters alike caused significant congruency effects when a task rule was applied. Subjects in the TS group responded faster when target and distracter were mapped to the same response, that is, when they belonged to the same category, than when their categories did not match. This effect occurred irrespective of whether the distracter was part of the target set or not. In contrast, in the SR group only target-related distracters interfered.

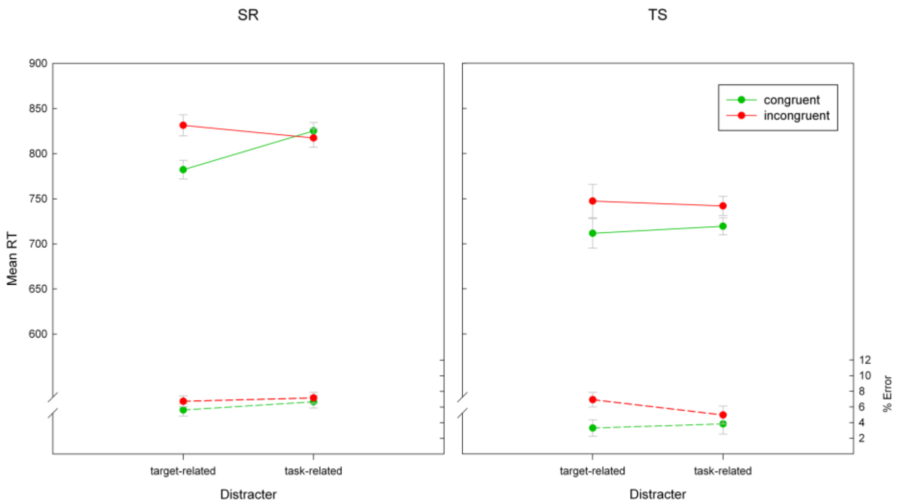

Figure 9. *Mean response times (RTs) in ms and error rates in % as a function of Instruction, Distracter, and Congruency in Experiment 2. Error bars represent inferential confidence intervals (Tryon, 2001) based on comparisons of congruent and incongruent trials.*

The interference that was observed for target-related distracters could have been due to retrieval of SR mappings from LTM. The distracters depicted objects that were part of the target set and therefore responded to repeatedly (albeit as words and not as pictures). In contrast, task-related distracters were not part of the target set. They were pictures of objects that were never responded to in the course of the experiment. They equally often accompanied targets that afforded a right hand response and a left hand response. Therefore, any incidental binding between a task-related distracter and a specific response due to mere co-occurrence of distracter and response is unlikely. Moreover, if any such stimulus-specific effects were to cause interference, the same would have been expected for task-related distracters in the SR condition. Yet, in that group of subjects task-related distracters did not interfere with target processing. In sum, Experiment 2 replicates the findings of Experiment 1: task-related distracters are categorized according to the rule and thereby interfere despite of (or possibly because of) shielding.

EXPERIMENT 3

One shortcoming of Experiment 2 is that the task was practiced extensively before the experimental blocks started. Target-related distracters were already shown during practice blocks, whereas task-related distracters were only introduced in the experimental blocks. Therefore, they might have attracted attention due to their novelty and might have motivated participants to expect them as upcoming targets. Experiment 3 served to remove the difference in time point of introduction as a possible confound. This time, all participants were informed about the task rule (TS condition only), which made it possible to skip the practice blocks and start the experiment with all possible compound stimuli from the very beginning. Note that at the beginning of the experiment participants were informed about all eight target words and the corresponding response keys. This should make it rather unlikely for them to expect irrelevant distracter pictures to appear as targets. In addition, in Experiment 2 I had opted for a completely random order of trial presentation, which resulted in almost a third of all trials being stimulus repetitions or negative priming trials that had to be excluded before analysis. Also, congruent compound stimuli where word and picture were identical were not shown in Experiment 2, so incongruent trials were slightly more frequent. Although I do not believe that these shortcomings influenced the results of Experiment 2 in favor of the hypothesis (for instance, a high frequency of incongruent trials usually reduces interference; see e.g. Logan & Zbrodoff, 1979), I revised them in Experiment 3. Now all possible word-picture compound stimuli including identical words and pictures were shown in a pseudo-random order.

METHOD

PARTICIPANTS

12 students from the University of Regensburg (12 women, mean age = 25 years, age range: 20-35 years) participated for partial course credit. All had normal or corrected to normal vision and were German native speakers. Participants signed informed consent and were debriefed after the session.

APPARATUS AND STIMULI

The same apparatus and stimuli as in Experiment 2 were used.

PROCEDURE

The procedure was the same as in Experiment 2 with the following exceptions: First, all participants were instructed to use the categorization rule. There was no SR group in Experiment 3. Second, words were not introduced stepwise and not practiced before the experimental blocks.

Instead, after announcement of the rule all targets and corresponding mappings were introduced on one slide. Three experimental blocks followed directly after this introductory slide without intervening practice trials. Last, compound stimuli where target and distracter depicted the same objects were not excluded from the experiment but removed before analysis. This ensured that congruent and incongruent compound stimuli occurred with the same probability. Trials were presented in pseudo-random order. Word repetitions, picture repetitions and negative priming trials were not allowed during the experiment.

DESIGN

A 3 (Block) X 2 (Distracter: target-related picture vs. task-related picture) X 2 (Congruency: congruent vs. incongruent) within-subjects design was used.

RESULTS

The preprocessing procedure was the same as in Experiment 1.

RT DATA

Results are depicted in Figure 10, and displayed in Table 5.

***Table 5**. Results from the main ANOVA conducted in Experiment 3. Significant results ($p \leq .05$) are printed in bold.*

	RT (ms)			Error rates (%)		
Effect	**F**	**p**	**η^2**	**F**	**p**	**η^2**
Block	**16.72**	**< .001**	**.60**	1.72	.20	.14
Distracter	1.78	.21	.14	**12.32**	**< .01**	**.53**
Congruency	**91.23**	**< .001**	**.89**	**46.55**	**< .001**	**.81**
Block X Distracter	< 1	.46	.07	< 1	.93	.01
Block X Congruency	< 1	.68	.03	< 1	.47	.07
Distracter X Congruency	3.18	.10	.22	**29.03**	**< .001**	**.73**
Block X Distracter X Congruency	< 1	.92	.01	< 1	.94	.01

A 3 (Block) X 2 (Distracter) X 2 (Congruency) repeated measures ANOVA revealed significant main effects of Block, $F(2,22) = 16.72$, $\eta_p^2 = .60$, and Congruency, $F(1,11) = 91.23$, $\eta_p^2 = .89$. RTs decreased with practice (block 1: 710 ms, block 2: 670 ms, block 3: 662 ms). As expected, congruent trials were answered faster than incongruent trials (657 ms vs. 705 ms). No other effects were significant, all $F < 3.2$, all $p > .1$.

ERROR RATES

Error data are also depicted in Figure 10 (see also Table 5). A 3 (Block) X 2 (Distracter) X 2 (Congruency) repeated measures ANOVA was performed. I found significant main effects of Distracter, $F(1,11) = 12.32$, $\eta_p^2 = .53$, and Congruency, $F(1,11) = 46.55$, $\eta_p^2 = .81$. Errors were more frequent with target-related distracters than with task-related distracters (7.2 % vs. 4.2 %), and subjects were more error-prone in incongruent than in congruent trials (8.3 % vs. 3.1 %). The two main effects were accompanied by a significant interaction Distracter X Congruency, $F(1,11) = 29.03$, $\eta_p^2 = .73$. Additional analyses revealed, that the congruency effect was significant for target-related distracters, $t(11) = 6.65$, but not for task-related distracters, $t(11) = 1.22$, $p = .25$.

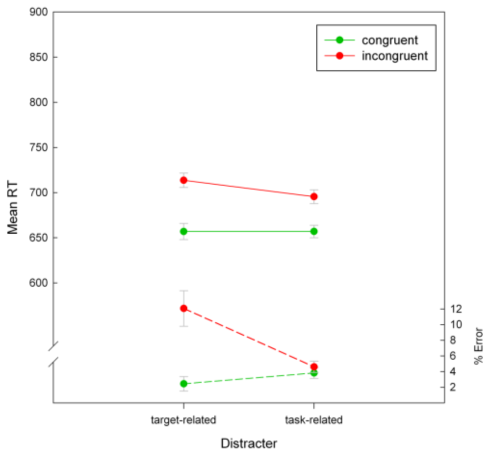

Figure 10*. Mean response times (RTs) in ms and error rates in % as a function of Distracter and Congruency in Experiment 3. Error bars represent inferential confidence intervals (Tryon, 2001) based on comparisons of congruent and incongruent trials.*

DISCUSSION

The results of Experiment 3 again replicate those of Experiments 1 and 2. A significant RT congruency effect was observed for target-related and task-related distracters. This time targets were not practiced and the distracters were all introduced simultaneously. The only difference between target-related and task-related distracters was whether they had an equivalent among the target words or not. At no time during the experiment were the task-related distracters specifically highlighted or responded to. Like in the previous experiments I suggest that interference for task-related distracters occurred because all distracters were categorized according to the task rule. The shielding function does not have the same effect on task-related distracters as it does on completely irrelevant information.

EXPERIMENT 4

One possible alternative explanation of the results of Experiment 3 is that categorization of the distracters was strategic rather than involuntary. 25 % of the distracters were target-related and congruent so one might argue that participants strategically relied on distracter information to speed up responses. Therefore, in Experiment 4 I tried to replicate the results of Experiment 3 with task-related distracters only. Using only distracters that were new to subjects should prevent strategic use of distracter information.

METHOD

PARTICIPANTS

18 students from the University of Regensburg (13 women, mean age = 24 years, age range: 20 - 33 years) participated for partial course credit or 4 €. All had normal or corrected to normal vision and were German native speakers. Participants signed informed consent and were debriefed after the session.

STIMULI AND PROCEDURE

24 German words and corresponding pictures were used. The words were split into three target sets of 8 words (4 moving and 4 non-moving objects each). Target set was counterbalanced across subjects. Pictures of the objects from the remaining two sets served as distracters. Thus, distracters were always task-related but never target-related. This resulted in 128 possible word-picture combinations (8 target words x 16 distracter pictures). Trial procedure was the same as in Experiment 3. After the instruction, subjects completed 3 blocks of 128 trials each.

DESIGN

A 3 (Block) X 2 (Congruency: congruent vs. incongruent) repeated measures design was used.

RESULTS

One subject was excluded from all analyses due to an error rate of almost 40 % (mean error rate was below 6 %).

RT DATA

A 3 (Block) X 2 (Congruency) ANOVA was conducted (see Table 6). Both main effects were significant. RTs decreased significantly with practice, $F(2,32) = 8.94$, $\eta_p^2 = .36$ (block 1: 771 ms, block 2: 725 ms, block 3: 690 ms). Most important, congruent trials were again answered faster than incongruent trials (721 ms vs. 737 ms), $F(1,16) = 5.21$, $\eta_p^2 = .25$. The interaction Block X Congruency failed to reach significance, $F = 1.7$, $p = .20$. An additional analysis revealed that congruent trials were answered significantly faster than incongruent trials already in block 1, $t(16) = 2.16$ (752 ms vs. 790 ms).

Table 6. *Results from the ANOVAs conducted in Experiment 4. Significant results (p ≤ .05) are printed in bold.*

	RT (ms)			Error rates (%)		
Effect	**F**	**p**	**η^2**	**F**	**p**	**η^2**
Block	**8.94**	**< .01**	**.36**	2.04	.15	.11
Congruency	**5.21**	**.04**	**.25**	**9.30**	**.01**	**.37**
Block X Congruency	1.71	.20	.10	< 1	.56	.04

ERROR RATES

A 3 (Block) X 2 (Congruency) ANOVA revealed a significant main effect of Congruency, $F(1,16) = 9.30$, $\eta_p^2 = .37$. Subjects committed more errors in incongruent trials than in congruent trials (6.5 % vs. 4.4 %). The main effect of Block and the interaction Block X Congruency were not significant, both $F < 2.1$, both $p > .14$.

DISCUSSION

Experiment 4 replicated the results of experiments 1-3. The distracters interfered with target processing although none of them had ever been part of the target set. Subjects responded faster and more accurately when word and picture belonged to the same category than when they belonged to different categories. This time, it can be ruled out that participants made strategic use of congruent distracters by presenting only task-related pictures.

CONCLUSIONS

In four experiments I found that in a two-choice categorization task irrelevant but task-related distracters interfered with target processing. Using word-picture compound stimuli where subjects had to categorize the word only I consistently found significant congruency effects for two types of distracters: pictures that were part of the target set and had an equivalent among the target words (target-related distracters), and pictures that were never presented as words but could be categorized according to the rule (task-related distracters). With both kinds of distracters subjects responded faster when target and distracter belonged to the same (novel) category than when they did not. Experiments 3 and 4 ruled out that expectations of future relevance or strategic use of the pictures produced the observed effects.

A congruency effect with target-related distracters has previously been reported (Dreisbach and Haider, 2009), but it did not allow to disentangle stimulus-specific from task-specific effects. Here, especially Experiment 2 provided evidence that the interference (at least for task-related distracters) cannot be ascribed to stimulus-specific effects since no interference was found in the SR condition. The result was taken as evidence for the automatic application of categorization rules. The shielding function of task sets which has previously been shown to affect information not related to the task seems to result in costs when the to-be-ignored distracters are members of the relevant categories. Put differently, shielding does not affect task-related distracters in the same way that it affects unrelated distracters.

The results presented here might seem to suggest that the interference Dreisbach and Haider (2009) observed for related distracters (which correspond to the target-related distracters in the present experiments) was also caused by erroneous rule application rather than being stimulus-specific. Yet, I want to emphasize that interference effects due to the erroneous categorization of irrelevant distracters does not mean that congruency effects such as the TRCE are generally task-specific. The effect I observed for target-related pictures might at least partly be stimulus-specific. Although the pictures themselves never served as targets, the objects they depicted were part of the target set and as such were part of the instruction and practiced with the corresponding mapping. Recently, Frings, Möller, and Rothermund (2013) found that responses can be retrieved from memory even if the modality of the target changes, showing that conceptual information can be integrated into an event file. Consequently, encountering the same conceptual information in a different presentation format (e.g. first as a target word and then as a picture) would lead to the retrieval of the corresponding response from LTM although the picture itself had never been reacted to. And in fact Experiment 1 brought up significantly higher congruency effects for target-related than for task-related distracters (31 ms vs. 14 ms). In the TS group of Experiments 2 and in Experiment 3 the interaction between Distracter and Congruency in RT was there descriptively but failed to reach significance (although in Experiment 3 the interaction was reliable for error rates). Hence, stimulus-specific interference due to retrieval of previously established SR episodes very probably added to the congruency effect I observed for target-related distracters. Yet, I want to emphasize again that they cannot explain the congruency effect for task-related distracters.

One limitation of the specific procedure used here should be addressed. In almost all Experiments (the only exception is Experiment 1) pictures served as distracters and words served as targets. This might be considered problematic concerning the interpretation and generalization of the results because semantic categorization is faster for pictures than for words (Glaser & Glaser, 1989; Smith & Magee, 1980). One might argue that the privileged access of pictures to semantic information alone accounts for the observed results. In fact, I do not believe that distracters that are categorized more slowly than targets would lead to similar congruency effects. It would arguably not be adaptive for the cognitive system to wait for the completion of distracter processing when the target has already been categorized. Therefore, I believe that the differences in speed of word and picture categorization allowed the paradigms employed for this thesis to work. Generalization to situations in which targets are processed faster than distracters might therefore be problematic. However, the interpretation of the results is not compromised by this limitation. Even if distracter pictures were processed faster than target words in the present experiments, the fact remains that the pictures interfered in some cases but not in others. Basing the current interpretations on different patterns of interference by picture distracters should be considered problematic only if the conditions were interference was expected differed in speed. More precisely, fast picture categorization might have differential effects on slow or fast response times. That is, if the conditions in which I found interference were all slower or faster than the conditions in which I did not find interference, the speed of picture categorization might account for the results. This is not the case[2]. Therefore, speed of processing does not refute the interpretations of the current results in terms of shielding.

In conclusion, the experiments presented here brought up clear evidence that novel categorization rules are applied to targets and distracters alike as indicated by congruency effects from task-related distracters. Accordingly, the shielding function of task sets works differently on distracters that can be categorized according to the rule. In order to decide what is shielded against, the shielding function seems to rely on the categories deemed relevant by the instruction. Anything pertaining to those categories might be considered potentially relevant (albeit not necessarily intentionally) and categorized, and is therefore a source of interference. Relevance – in this case – might be defined as getting access to the response system. Shielding is only selective insofar as distracting information does not fall into the instructed categories. Whenever information fitting these categories is offered, shielding does not prevent interference. This seems reasonable assuming that outside the rather artificial experimental context task-related information is likely to be relevant. Being distracted by the rum in the grocery store when shopping for cocktail ingredients might be unnecessary, but more often than not when a stimulus offers potentially significant attributes it is

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[2] This is best illustrated later on by repetition trials in Experiments 5 and 6 (Part III). In Experiment 5, subjects were faster in the noun task than in the adjective task, whereas in Experiment 6 it was the other way around. Still, in both experiments I found congruency effects in the noun task but not in the adjective task.

actually behaviorally relevant. After all, one of the great advantages of rule use is their generalizability (remember the child learning that it should not eat green fruit).

On a different note, together with previous results the findings presented here allow one to hypothesize about the mechanism underlying the shielding function. They suggest that an activated task rule leads to enhanced processing of task-related information thereby causing interference from information that fits this criterion. So far, no indication of shielding as an inhibitory function (which leads to the suppression of irrelevant distracters) has been found. The second set of studies served to directly test the hypothesis that shielding is served by enhanced processing of task-related information rather than an alternative strategy such as inhibition of irrelevant distracters.

PART III

SHIELDING IN THE CONTEXT OF RANDOM TASK SWITCHING

INTRODUCTION

Investigations on the shielding function of task sets were first motivated by results from the task switching literature. At first, in order to unveil potential benefits of rule use the switching paradigm was abandoned and the use of a single rule was compared to an SR strategy (Dreisbach & Haider, 2008, 2009). Only in 2011 did Dreisbach and Wenke return to task switching. They found that shielding is only intact on task repetitions but reduced on switch trials. A conclusion that can be drawn from this finding is that the level of rule activation plays a crucial role in shielding. The fact that irrelevant stimulus features were successfully shielded against on task repetitions but got access to the response system on task switches suggests that the shielding function critically depends on the degree of activation of the current task. Because in the study by Dreisbach and Wenke the task was only indicated with the onset of the univalent target (i.e. without previous knowledge or pre-cues), activation of the relevant task was presumably lower on task switches than it was on task repetitions. Activation from the preceding trial could have been carried over into the next trial thereby providing an activation advantage on task repetitions (e.g. Allport, Styles, & Hsieh, 1994). In this vein, in the present thesis it was assumed that shielding is reduced on task switches when the task-rule has not been fully activated. In contrast, shielding is intact with full task activation on task repetitions. The idea that the shielding function is a consequence of task activation might appear trivial. Yet, it is *not*: remember that there is *no shielding* when participants are not informed about a common, response-defining stimulus feature but instead apply arbitrary SR mappings. That is, the activation of the SR mappings alone does not result in reduced susceptibility to irrelevant information. Only with a categorization rule can irrelevant information successfully be shielded against.

In the present two studies the reduction of shielding was used as a means for uncovering the mechanisms underlying the shielding function. More precisely, the reduction of shielding on task switches was used to assess whether shielding is a consequence of advantages in processing of task-related information (shielding$_{ADV}$ hereafter), or of the suppression of distracting information (shielding$_{SUP}$ hereafter). Let us return to your grocery shopping for cocktail ingredients. Your shopping is not affected by seeing cheese or flour. It is solely based on your need for cocktail ingredients. But why is that? Is it because the rule enables you to suppress any irrelevant information such as cheese or flour? Or is it because you now preferentially look for any cocktail ingredient? In this example common sense would indicate the latter. Yet, the concept of inhibition is very popular in many fields of psychology and should therefore not be discarded easily. For instance, in the domain of memory it is often assumed that retrieval induced forgetting is caused by the inhibition of competing representations (M. C. Anderson, Bjork, & Bjork, 1994). Likewise, intention formation (e.g.

Press the spacebar whenever the word elephant *or* lion *appears*) can result in the inhibition of distracting information. In this case, distracters would be words that are semantically related to *elephant* and *lion*, for instance *giraffe* (Veling & van Knippenberg, 2008). Another example with more relevance regarding the present thesis is the assumed inhibition of abandoned task sets that was addressed in the theoretical background (see Part I, e.g. M. Hübner et al., 2003; Mayr & Keele, 2000). In sum, inhibition is a popular explanation for a variety of phenomena and has repeatedly been found to affect performance when task rules are used. Yet, there is already empirical evidence indicating that – roughly put – common sense might be right in the case of your shopping experience. Dreisbach and Wenke (2011) found that changes of an irrelevant stimulus feature interacted with the response on task switch trials but not on task repetitions. However – so they argued – in order to know whether a feature was switched or repeated on a task switch it must have been processed on a preceding repetition trial, too. That is, although shielding was intact on task repetitions, the irrelevant feature was processed to a degree that allowed assessing whether it switched or repeated on the subsequent trial. Additional evidence for the shielding$_{ADV}$ account comes from Experiments 1 - 4 of the present thesis. The fact that task-related distracters were not shielded against suggests an advantage for potentially relevant information rather than suppression of distraction. However, direct evidence for the shielding$_{ADV}$ account is still missing and is the aim of the present experiments.

In addition to the mechanism underlying the shielding function, the following experiments allowed the investigation of the strength of shielding in a switching context. The question was, whether an active task can prevent interference from a recently activated but currently inactive rule. Until now shielding had only been investigated with completely irrelevant distracters (e.g. spatially oriented animals) or with distracters that were associated with the currently active task rule (target-related and task-related distracters). But what if subjects switch between tasks and the distracters are not related to the currently relevant but to the currently irrelevant task? How does the shielding function affect such information?

In the following experiments I applied the task switching paradigm. Again, participants had to respond to target words that were superimposed on distracter pictures. They switched between a noun categorization task and an adjective categorization task. The type of target word (noun vs. adjective) directly indicated the task. With such univalent targets no further task cues were necessary. Distracter pictures were line drawings that depicted either objects used as target words in the noun task (noun distracters) or new objects that could be categorized according to the noun task but never appeared as target words (noun-related distracters)[3]. This setup allows to measure effects

[3] In the noun task this corresponds to the target-related and task-related distracters used in Experiments 1 - 4. This is not true for the adjective task, to which none of the distracters bore reference.

of distracter interference separately for trials in which the distracters belong to the currently active task rule (in the noun task) and for trials in which they do *not* belong to the currently active task rule (in the adjective task). Differences between noun distracters and noun-related distracters will inform about the source of the interference as will be outlined below. Moreover, interference in conditions with reduced shielding (i.e. task switch trials) can be looked into. My predictions are as follows:

PREDICTIONS FOR TASK SWITCHES AND TASK REPETITIONS

The expected outcomes are depicted in Figure 11. From inspection of the figure it is apparent that predictions do not differ for task repetitions but that shielding$_{ADV}$ and shielding$_{SUP}$ make different predictions for switches to the noun task. Therefore, the hypotheses will be introduced separately for task repetitions and task switches.

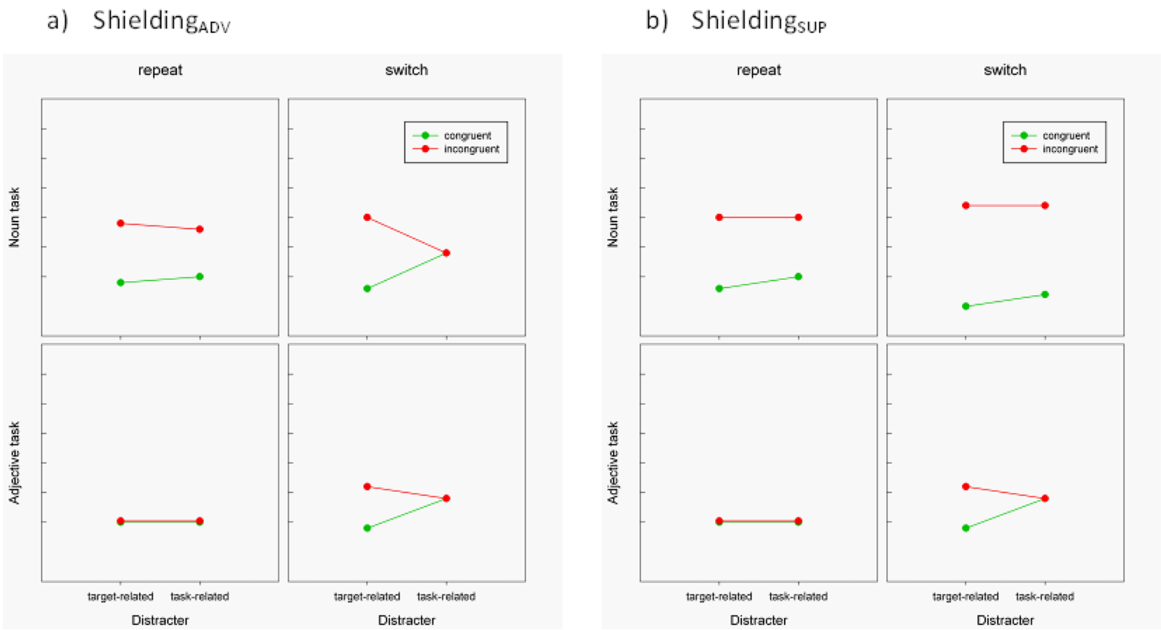

Figure 11. *Predictions from a) the shielding$_{ADV}$ account and b) the shielding$_{SUP}$ account.*

For *task repetitions*, a congruency effect is expected in the noun task, but not in the adjective task. In the noun task, congruency effects for both kinds of distracters would replicate results from Experiments 1 - 4. There I argued that distracters with task-related features are automatically categorized, thereby interfering with target categorization and resulting in congruency effects. As was outlined above, the fact that noun-related distracters interfere on noun task repetitions already points to preferred processing of task-related information. Still, because this result was obtained in the preceding experiments I considered it as a given and included it in the predictions for both accounts. In the adjective task, the distracters do not have any task-related attributes. Therefore – if shielding is indeed a function of rule use and activation – noun distracters and noun-related distracters should not interfere on adjective task repetitions according to shielding$_{ADV}$ as well as shielding$_{SUP}$. According to shielding$_{ADV}$ they would not interfere because adjective task information is preferentially processed, whereas according to shielding$_{SUP}$ they should be inhibited on adjective task repetitions.

For *task switches*, shielding$_{ADV}$ and shielding$_{SUP}$ make the same predictions regarding the adjective task. Noun distracters should interfere, whereas no congruency effect is expected for noun-related distracters. Noun-related distracters should not be categorized in the adjective task simply because the rule they are related to is currently not relevant. On the other hand, noun distracters can interfere by way of episodic retrieval of event files (Hommel, 1998; Logan, 1988). That is, while performing the noun task, targets are bound to their respective responses which then can be retrieved automatically whenever the target is encountered again. When shielding is reduced on switches to the adjective task, this stimulus-specific retrieval of event files should result in congruency effects for noun distracters because either preferential processing is not yet strong (, shielding$_{ADV}$) or because they are not yet efficiently inhibited (shielding$_{SUP}$). This argument gets further support from the fact that stimulus-specific effects are often increased on task switches (e.g. Rogers & Monsell, 1995; Yamaguchi & Proctor, 2011). Note though that in order for pictures to lead to the retrieval of a response associated with a corresponding word, it must be assumed that event files include conceptual information (Frings et al., 2013).

Finally and most important, shielding$_{ADV}$ and shielding$_{SUP}$ predict different outcomes for switches to the noun task. According to shielding$_{SUP}$, a reduction of shielding is tantamount to a reduction of suppression of irrelevant information. Consequently, when distracters are less efficiently suppressed interference should be increased. Put differently, regarding any distracter, in the case of shielding$_{SUP}$ the strength of shielding is inversely related to the strength of interference. That is, strong shielding results in a lack of interference, whereas an increase in interference is attributed to a reduction of shielding. Therefore, shielding$_{SUP}$ predicts that both noun-related distracters and noun distracters should interfere more on task switches when shielding is reduced. In contrast, shielding$_{ADV}$ assumes that a reduction of the shielding function goes along with a reduced processing advantage for task-related information. This should mainly affect congruency effects caused by noun-related distracters. Since their task-relevant features are now *not* as preferentially processed they should not interfere. Hence, the shielding$_{ADV}$ account predicts a congruency effect for noun distracters (for the same reasons as on switches to the adjective task, see above) but not for noun-related distracters.

Overall, statistically, I predict an interaction Task X Congruency for task repetitions, with congruency effects in the noun task but not in the adjective task. For task switches, an interaction

Distracter X Congruency would indicate shielding$_{ADV}$: Noun distracters should interfere in both tasks, noun-related distracters in neither task. In contrast, a significant triple interaction Task X Distracter X Congruency would be indicative of shielding$_{SUP}$: In this case, the interaction Distracter X Congruency should be significant in the adjective task, but not in the noun task.

EXPERIMENT 5

METHOD

PARTICIPANTS

Thirty-two students from the University of Regensburg (26 women, mean age = 23 years, age range: 18 - 47 years) participated for partial course credit. All had normal or corrected to normal vision and were German native speakers. Participants signed informed consent and were debriefed after the session.

STIMULI AND PROCEDURE

Sixteen German nouns and eight adjectives served as target stimuli (see Table 7). Sixteen line drawings depicting the nouns served as distracters.

Table 7. *German nouns and adjectives used in Experiments 5-7. English translations are added in parentheses.*

Nouns Set A	Nouns Set B	Adjectives Exp 5	Adjectives Exp 6/7
Schaukel *(swing)*	Jojo *(yoyo)*	trocken *(dry)*	warm *(warm)*
Koala *(koala)*	Glocke *(bell)*	rot *(red)*	glühend *(glowing)*
Wolke *(cloud)*	Traktor *(tractor)*	alkoholisch *(alcoholic)*	schwül *(hot and humid)*
Kreisel *(spinning top)*	Bein *(leg)*	flüssig *(fluid)*	kochend *(boiling)*
Schemel *(stool)*	Jacke *(jacket)*	rockig *(rocking)*	eisig *(icy)*
Kamm *(comb)*	Gürtel *(belt)*	laut *(loud)*	frierend *(freezeing)*
Weste *(vest)*	Truhe *(chest)*	feierlich *(ceremonial)*	kühl *(cool)*
Kaktus *(cactus)*	Berg *(mountain)*	melodisch *(melodic)*	klirrend *(crisp cold)*

The line drawings were taken from the Snodgrass collections (Csycowicz, Friedman, Rothstein, & Snodgrass, 1997; Snodgrass & Vanderwart, 1980). Target words were superimposed on distracter pictures (see Figure 12). They were presented in size 18 Arial font and purple color. Compound stimuli appeared in the center of the screen against a white background. Subjects switched randomly between a noun and an adjective task. If a noun appeared, it had to be categorized as a *moving* or a *non-moving object*. Adjectives had to be categorized as *describing wine* or *music*.

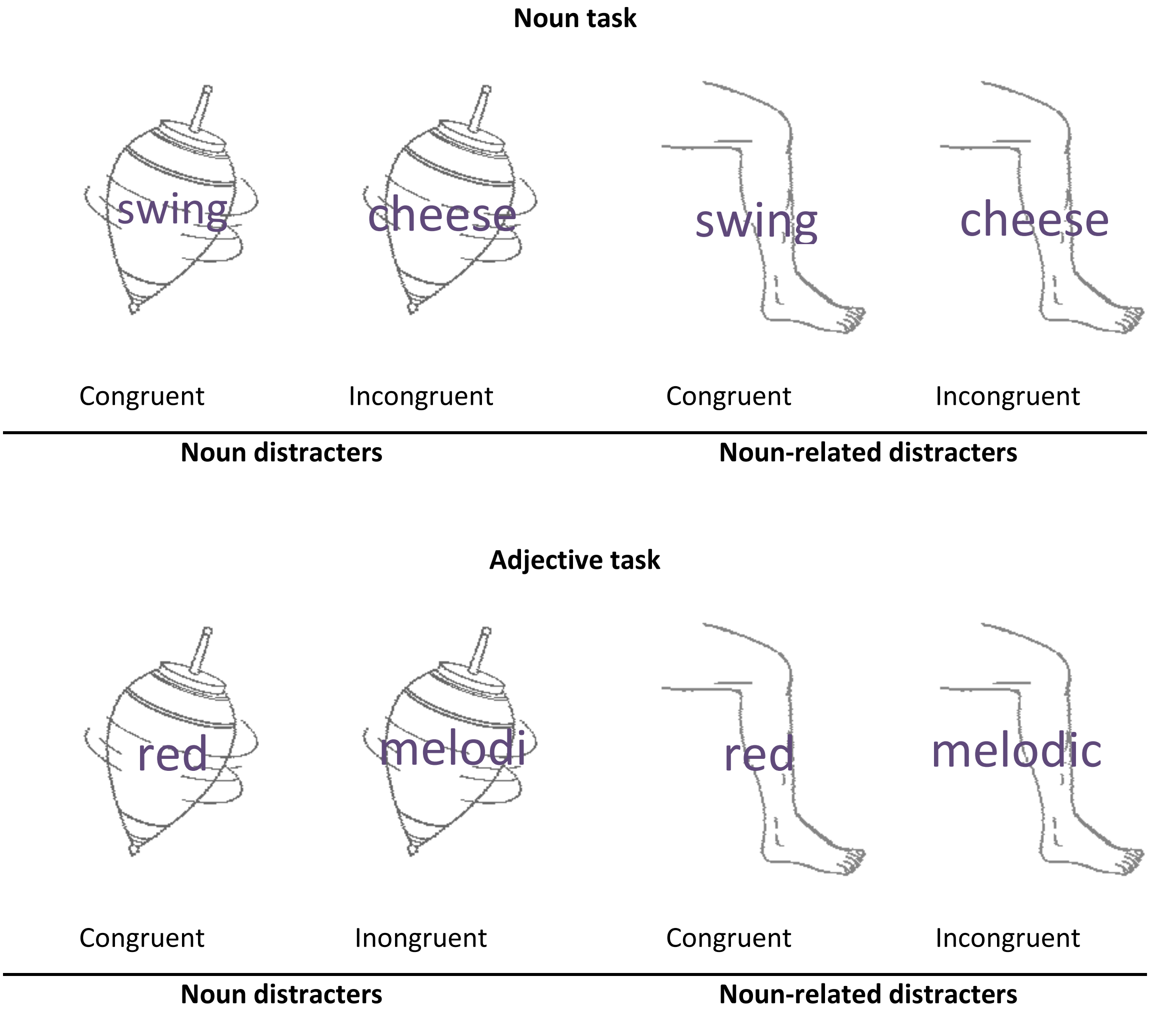

Figure 12. *Examples for the compound stimuli from Experiment 5. In this case nouns representing moving objects and adjectives describing wine are mapped to the same response. The compound stimuli are illustrative and do not match the stimuli used in the experiment exactly in size and position.*

Subjects responded by pressing a left or a right response key on a standard QWERTZ-keyboard (“y”- and “m”- key). Category-response mappings were counterbalanced across subjects. The 16 nouns were split into two sets of eight nouns. For a given subject, only the nouns from one set were used as targets. Accordingly, half of the distracter pictures depicted objects that were also used as target words in the noun task (noun distracters). The other half of the distracters depicted objects that never appeared as target words but still were related to the noun task inasmuch as they could be categorized as moving or non-moving objects (noun-related distracters). None of the distracters were related to the adjective task. Target and distracter could be response-congruent or incongruent, depending on the category they belonged to and the associated responses. For instance, the target word *melodic* and the distracter picture of a stool would be response-congruent if the categories *describing music* and *non-moving object* were mapped to the same response key. If they were mapped to different response keys, the word *melodic* and the picture of a stool would be response incongruent.

A trial started with a fixation cross (500 ms) followed by a blank screen (500 ms). Then the imperative word-picture compound stimulus appeared and remained on the screen until a response was given. A 500 ms feedback appeared on every trial: A correct response was followed by a green fixation cross, a red fixation cross indicated an error (see Figure 13).

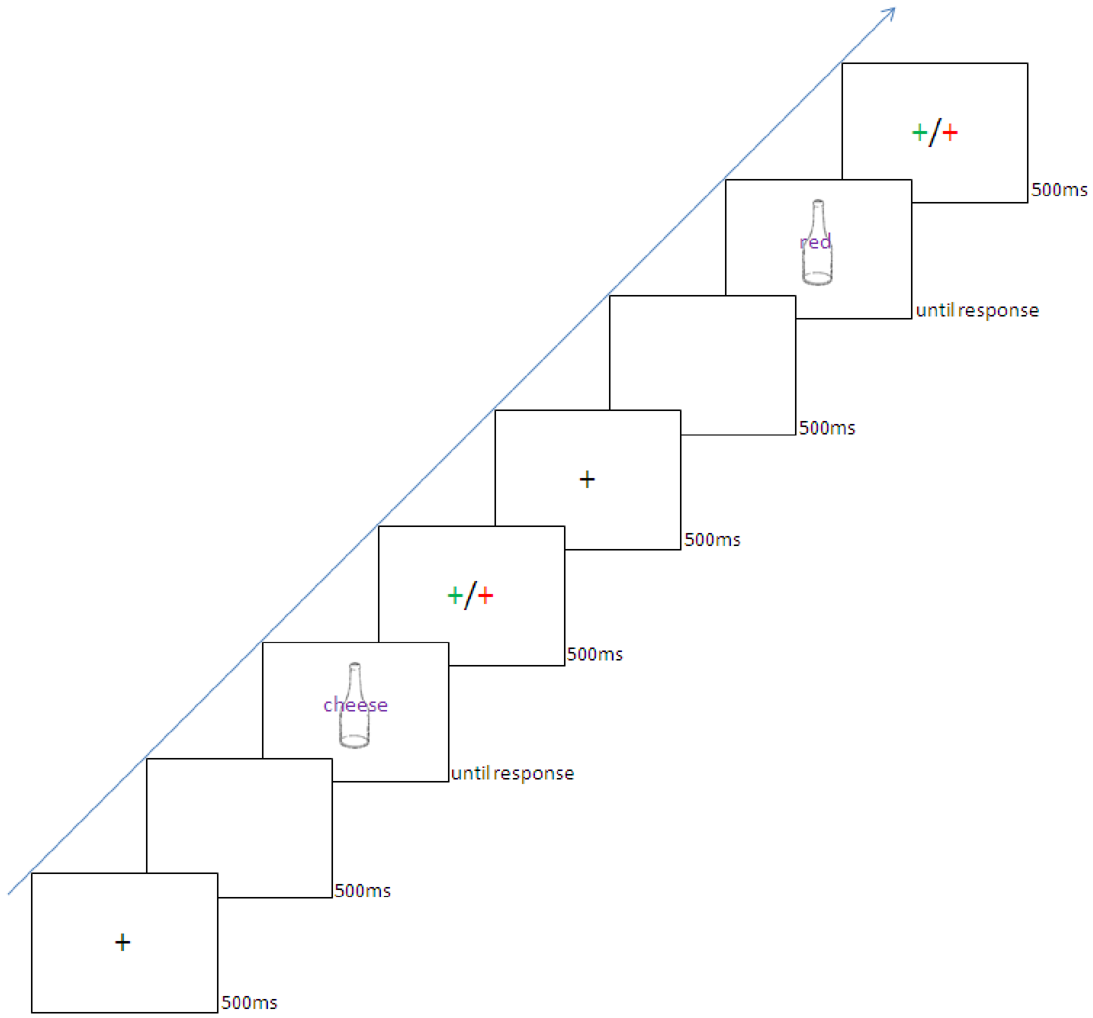

Figure 13*. Trial procedure in Experiment 5. In the figure, two consecutive trials are depicted, one noun task trial, and one adjective task trial, respectively.*

Subjects were informed about the tasks and the corresponding mappings via written instructions and saw a slide showing all 16 potential targets (eight nouns and eight adjectives). Both speed and accuracy were stressed. Before the Experiment proper, subjects completed two short single task blocks and one mixed task block for practice. In the single task blocks every target was presented twice in random order without any distracters, resulting in a block length of 16 trials per task. In the mixed task practice block, subjects randomly switched between the noun task and the adjective task. Half of the trials were task repetitions. In this mixed block, target words were already superimposed on the distracter pictures. Every possible word-picture combination was shown once, resulting in 256 trials ([8 nouns + 8 adjectives] x 16 distracter pictures). Word repetitions, picture repetitions and negative priming trials were not allowed. After the mixed practice block two experimental blocks with the same specifications followed.

Design

A 2 (Task: nouns vs. adjectives) X 2 (Sequence: switch vs. repeat) X 2 (Distracter: noun vs. noun-related) X 2 (Congruency: congruent vs. incongruent) repeated measures design was used.

Results

In this and the following experiment the same preprocessing procedure was applied: Only the two experimental blocks were analyzed. The first trial of a given block and trials where target and distracter depicted the same object were excluded from all analyses (3.5 %). Moreover, error trials and trials following an error were excluded from RT analysis (Experiment 5: 9.2 %; Experiment 6: 7.4 %). To correct for outliers, RTs exceeding two standard deviations from the individual cell mean were also excluded from RT analysis (Experiment 5: 5.6 %; Experiment 6: 5.6 %). I adopted a significance level of .05 in all analyses. Individual *p*-values for significant effects are not reported in the text.

In Experiment 5, two subjects were excluded from analysis. One committed errors in more than 20 % of the trials (mean error rate was below 5 %). The other participant reported having combined the two rules into one superordinate rule, making switching unnecessary. One subject completed only one experimental block due to a software error. Overall, data from 30 participants were included in the final analyses.

2 (Task: nouns vs. adjectives) X 2 (Sequence: switch vs. repetitions) X 2 (Distracter: noun vs. noun-related) X 2 (Congruency: congruent vs. incongruent) repeated measures Analyses of Variance (ANOVAs) were conducted on RT and error rates. Table 8 lists the results of these ANOVAs. For specific values of F, p, and η^2 the reader is referred to this table. In the text, I will mostly focus on RT results. The error pattern did not contradict RT results.

Table 8*. Results from the main ANOVAs conducted in Experiment 5. One overall ANOVA included the factors Task, Sequence, Distracter, and Congruency. Separate ANOVAs were then conducted for repeat trials only and switch trials only. Significant results ($p \leq .05$) are printed in bold.*

		overall			**repeat trials only**			**switch trials only**		
Effect		**F**	**p**	**η^2**	**F**	**p**	**η^2**	**F**	**p**	**η^2**
Task	RT (ms)	**12.64**	**< .01**	**.30**	**5.50**	**.03**	**.16**	**12.48**	**< .01**	**.30**
	Errors (%)	*< 1*	*.55*	*.01*	*< 1*	*.37*	*.03*	*< 1*	*.85*	*.00*
Sequence	RT (ms)	3.73	.06	.11	-	-	-	-	-	-
	Errors (%)	***5.95***	***.02***	***.17***	-	-	-	-	-	-
Distracter	RT (ms)	< 1	.42	.02	< 1	.81	.00	1.08	.31	.04
	Errors (%)	***8.78***	***< .01***	***.23***	*4.40*	*.05*	*.13*	*3.87*	*.06*	*.12*
Congruency	RT (ms)	**20.91**	**< .01**	**.42**	**18.24**	**< .01**	**.39**	**9.09**	**< .01**	**.24**
	Errors (%)	***41.03***	***< .01***	***.59***	***15.33***	***< .01***	***.35***	***26.36***	***< .01***	***.48***
Task X Sequence	RT (ms)	**4.78**	**.04**	**.14**	-	-	-	-	-	-
	Errors (%)	*< 1*	*.53*	*.01*	-	-	-	-	-	-
Task X Distracter	RT (ms)	< 1	.88	.00	< 1	.33	.03	1.47	.24	.08
	Errors (%)	*< 1*	*.42*	*.02*	*< 1*	*.44*	*.02*	*< 1*	*.55*	*.01*
Sequence X Distracter	RT (ms)	< 1	.46	.02	-	-	-	-	-	-
	Errors (%)	*< 1*	*.91*	*.00*	-	-	-	-	-	-
Task X Sequence X Distracter	RT (ms)	2.44	.13	.08	-	-	-	-	-	-
	Errors (%)	*< 1*	*.96*	*.00*	-	-	-	-	-	-
Task X Congruency	RT (ms)	**12.52**	**< .01**	**.30**	**8.23**	**< .01**	**.22**	**4.89**	**.04**	**.14**
	Errors (%)	*3.87*	*.06*	*.12*	*< 1*	*.34*	*. 3*	***5.72***	***.02***	***.17***
Sequence X Congruency	RT (ms)	1.18	.29	.04	-	-	-	-	-	-
	Errors (%)	*< 1*	*.56*	*.01*	-	-	-	-	-	-
Task X Sequence X Congruency	RT (ms)	< 1	.90	.00	-	-	-	-	-	-
	Errors (%)	*1.26*	*.27*	*.04*	-	-	-	-	-	-
Distracter X Congruency	RT (ms)	**11.85**	**< .01**	**.29**	< 1	.95	.00	**10.95**	**< .01**	**.27**
	Errors (%)	***11.10***	***< .01***	***.28***	*3.12*	*.08*	*.10*	***9.21***	***< .01***	***.24***
Task X Distracter X Congruency	RT (ms)	.22	.64	.01	< 1	.1	.00	< 1	.51	.02
	Errors (%)	***13.03***	***< .01***	***.31***	***10.43***	***< .01***	***.27***	***6.31***	***.02***	***.18***
Sequence X Distracter X Congruency	RT (ms)	4.80	.04	.14	-	-	-	-	-	-
	Errors (%)	*1.07*	*.31*	*.04*	-	-	-	-	-	-
Task X Sequence X Distracter X Congruency	RT (ms)	< 1	.59	.01	-	-	-	-	-	-
	Errors (%)	*< 1*	*.99*	*.00*	-	-	-	-	-	-

As can be seen in Table 8 the four-way interaction was non-significant. Still, because the predictions regarding repetition trials and switch trials were very specific I split the data and conducted two separate three-way ANOVAs including the factors Task, Distracter, and Congruency.

The results are also listed in Table 8 and depicted in Figure 14. For the sake of clarity, in the text I will focus on the specific interactions that are important with respect to my predictions.

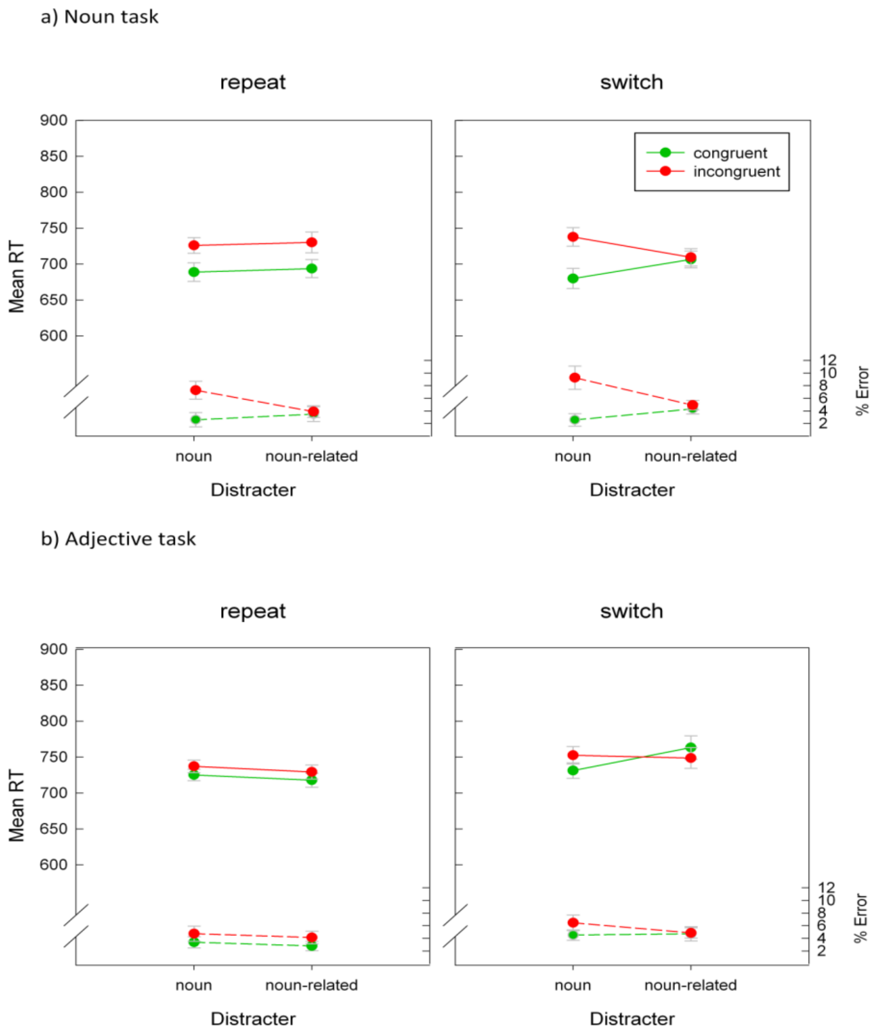

Figure 14. *Mean response times (RTs) in ms and error rates in % as a function of Task, Sequence, Distracter and Congruency in Experiment 5. Error bars represent inferential confidence intervals (Tryon, 2001) based on comparisons of congruent and incongruent trials.*

For task repetitions, the predicted interaction Task X Congruency was significant. Additional contrasts showed that the overall congruency effect was present in the noun task, $F\,(1,29) = 30.39$, $\eta^2 = .51$, but non-significant in the adjective task, $F\,(1,29) = 1.85$, $p = .18$. On task switch trials, the Distracter X Congruency interaction predicted by the shielding$_{ADV}$ account was significant. There was a significant congruency effect for noun distracters, $t(29) = 4.85$, whereas no such effect was found for noun-related distracters, $t(29) < 1$, $p = .54$. The higher order interaction involving Task that would have supported the shielding$_{SUP}$ account failed to reach significance in RTs, $F < 1$, $p > .5$. Interestingly, for error rates the interaction Task X Distracter X Congruency was significant, $F\,(1,29) = 6.31$, $\eta^2 = .18$.

However, this triple interaction did not resemble the pattern predicted by the shielding$_{SUP}$ account. Descriptively, Distracter and Congruency interacted in both tasks, yet the interaction was only significant in the noun task, $F(1,29) = 13.03$, $\eta^2 = .31$. Remember that shielding$_{SUP}$ would have predicted the interaction to be significant only in the adjective task.

DISCUSSION

In the discussion I will focus on RT data. Subjects made few errors and error data did not counteract the RT data pattern. RT results of Experiment 5 show that in a switching context task shielding is present on task repetitions but reduced on task switches thereby confirming previous results (Dreisbach & Wenke, 2011). When the adjective task was repeated, shielding was intact and prevented interference from distracters related to the competing task: Distracter pictures that were semantically related to the noun task did not lead to congruency effects in the adjective task. In contrast, when the noun task was repeated I found significant congruency effects for noun distracters and noun-related distracters. Subjects responded faster when the target word and the distracter picture were from the same category than they were from different categories. The results from noun task repetitions thus replicate the findings from Experiments 1-4. Even distracters that never occurred as targets were automatically categorized according to the currently active task rule. In Part II of the present thesis I already ruled out that the interference by noun-related distracters was due to stimulus-specific retrieval processes and the results presented here support this finding. So, here I could show again that the shielding mechanism does not prevent but actually may cause interference from distracters that are related to the task that is currently executed.

On switches, Distracter and Congruency interacted without a significant mediating effect of Task. That is, on switches, noun distracters interfered, whereas noun-related distracters did not. For the adjective task, this suggests stimulus-specific interference effects on switch trials caused by retrieval of event files or episodes acquired during the noun task (Hommel et al., 2001; Logan, 1988). Note that I can rule out that erroneous rule-application caused the interference when switching to the adjective task. If this had been the case, noun-related distracters should have interfered, too. It should be stated though, that although categorization according to the noun rule was not the reason for the observed congruency effect, I cannot rule out entirely that it occurred. The distracter pictures might have been categorized by mistake, but simply might not have resulted in strong enough evidence for the particular response associated with that category to interfere (Schneider & Logan, 2005, 2009).

Even though the interference from noun distracters on switches to the adjective task is indicative of reduced shielding, it is not suited to decide between shielding$_{SUP}$ and shielding$_{ADV}$. Both, reduced suppression of the noun distracters (shielding$_{SUP}$) as well as less preferred processing of adjective task information (shielding$_{ADV}$) might have resulted in the observed interference. However, for switches to the noun task, shielding$_{ADV}$ predicted that the processing advantage for task-related information should attenuate interference from noun-related distracters relative to noun task repetitions. And indeed, on task switch trials, noun-related distracters interfered less than noun distracters, as can be seen from the significant interaction Distracter X Congruency. No such interaction was found on task repetitions, in which both noun and noun-related distracters interfered to the same extent. This is taken as evidence for the shielding$_{ADV}$ account. Remember that the shielding$_{SUP}$ account would have predicted *increased interference* from the distracters on task switches as a consequence of reduced distracter suppression.

A possible problem for the interpretation of the results in terms of the shielding$_{ADV}$ account is that interference by noun distracters might have been expected to be greater on task repetitions than on task switches. On task switches, supposedly, episodic retrieval alone produces interference effects. On the other hand, on task repetitions both retrieval and categorization should add up to produce even stronger congruency effects for noun distracters. However, as can be inferred from the lack of interference from noun distracters on adjective task repetitions, automatic episodic retrieval does not appear to be a strong source of interference on task repetitions where shielding is intact. Consequently, if – on task repetitions – interference by episodic retrieval is less effective while interference due to automatic categorization is enhanced, this might in sum produce comparable congruency effects for task repetitions and task switches for noun distracters.

The fact that I found no congruency effect for either of the distracters on adjective task repetitions is contrary to typical findings in the task switching paradigm when looking at the TRCE. When subjects switch between two tasks with bivalent stimuli (e.g. switching between two digit categorization tasks), performance mostly is not only affected by task sequence (repetition vs. switch) but also by SR mappings related to the competing task. According to such findings one might have expected that task shielding would not prevent interference from information that is related to a competing task (in this case the noun task). However, the TRCE is typically found with *bivalent* stimuli where both tasks can be applied to different features of a single target, whereas task shielding has mostly been observed for stimulus features that are unrelated to the currently active task rule (e.g. stimulus color) or separate distracter stimuli that never become task relevant (e.g. background pictures).

The entire interpretation of the results so far rests upon the assumption that participants switched between task rules. This, however, might be called into question because switch costs were very small (10 ms). A closer inspection of the results shows that switch costs were present in the adjective task (21ms), and only their absence in the noun task resulted in the overall non-significant cost. Furthermore, the differential interference effects found for switch and repeat trials and the significant switch costs in error rates clearly speak in favor of separate rule application. The issue of the small switch cost will be discussed further in the Conclusions of Part III.

In sum, the results of Experiment 5 support the assumption of a shielding function of task sets that prevents interference from distracters related to a competing task on task repetitions, and is reduced on task switches. The fact that this reduced shielding resulted in attenuated interference from noun-related distracters in the noun task is taken as evidence for the shielding$_{ADV}$ account.

EXPERIMENT 6

Experiment 6 served two purposes. First, I wanted to replicate the results of Experiment 5 with respect to noun distracters. Since the TRCE is a robust finding with bivalent stimuli, my intention was to replicate the lack of interference from noun distracters on task repetitions in the adjective task. Second, I wanted to gain further evidence for the shielding$_{ADV}$ account. In Experiment 6 I therefore replaced the noun-related distracters with pictures of spatially oriented animals. They served to further investigate interference on task switches. Dreisbach and Haider (2009) found that without shielding (i.e. when subjects used individual SR mappings but no task rule) spatially oriented animal distracters produced significant congruency effects whereas no such effect occurred when participants applied a categorization rule (which was not related to the animals). So, from previous studies it is known that pictures of spatially oriented animals do interfere in the absence of task shielding. Therefore, I used these spatially oriented animal distracters instead of noun-related distracters in Experiment 6. Note that animal distracters are always moving objects and therefore categorically congruent with half of the noun stimuli (orthogonally to being spatially response congruent with a given target stimulus, see Methods). Therefore, I will restrict the predictions to the adjective task. Both, the shielding$_{ADV}$ and the shielding$_{SUP}$ account predict no interference by any of the distracters on task repetitions. Also, both predict distracter interference for noun distracters on. So far, the data pattern would mirror the results from Experiment 5. However, for animal distracters the shielding$_{ADV}$ and the shielding$_{SUP}$ account make different predictions: The reduced processing advantage for task-related information should not have any effect on the processing of spatially oriented animal distracters, because their spatial orientation is still not related to any of the tasks. Consequently, even reduced shielding (as opposed to completely absent shielding) should not result in interference effects. On the other hand, shielding$_{SUP}$ would predict interference by spatially oriented animals as observed previously (e.g. Dreisbach & Haider, 2009). Less efficient suppression of the spatial information conveyed by the animals should result in a congruency effect.

Statistically, for the adjective task, the shielding$_{ADV}$ account predicts a three-way interaction Sequence X Distracter X Congruency. On the other hand, the shielding$_{SUP}$ account predicts an interaction Sequence X Congruency only. For the noun task, no predictions regarding spatial distracters are made for the reason mentioned above.

METHOD

PARTICIPANTS

Thirty-two students from the University of Regensburg (27 women, mean age = 21 years, age range: 18–26 years) participated for partial course credit. Participants signed informed consent and were debriefed after the session.

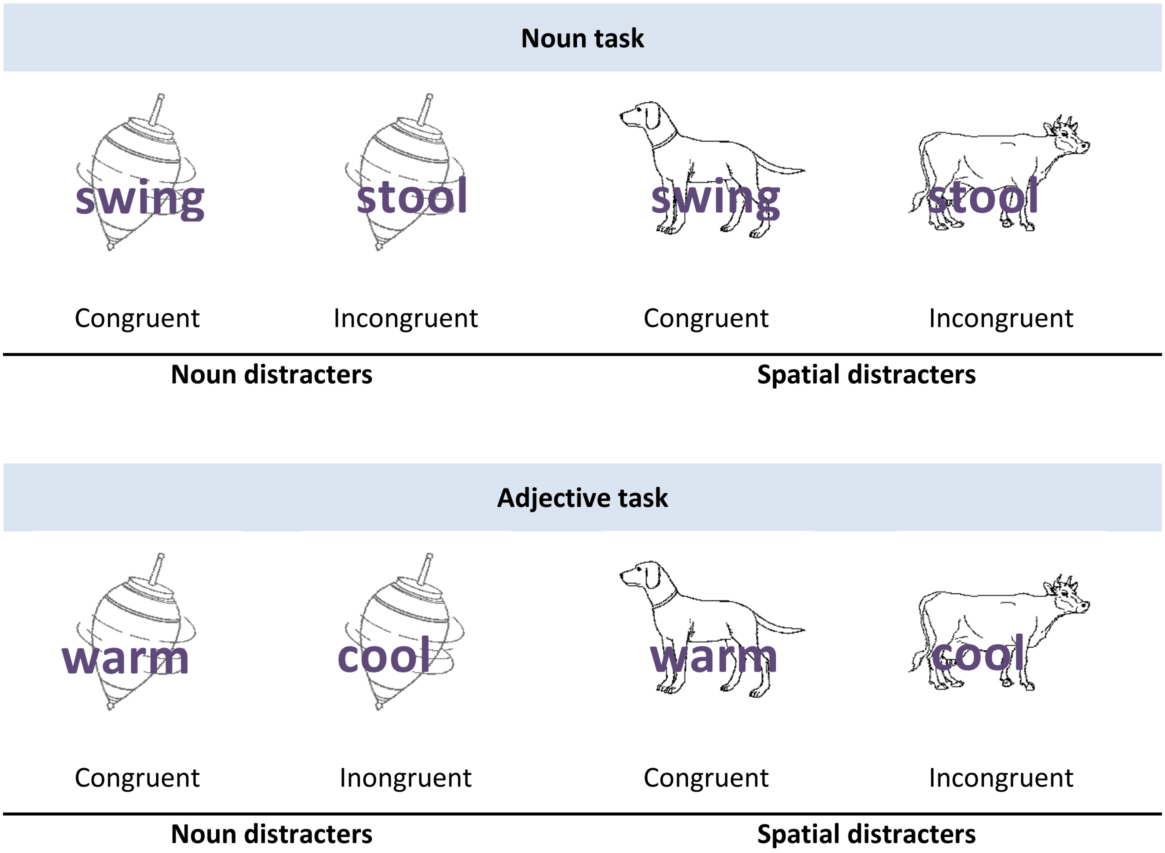

Figure 15. *Examples for the compound stimuli used in Experiment 6. The compound stimuli are illustrative and do not match the actual stimuli exactly in size and position.*

STIMULI AND PROCEDURE

Stimuli and procedure were the same as in Experiment 5 with two exceptions. First, instead of categorizing adjectives as describing wine or describing music, subjects had to categorize eight adjectives according to the *rule describes heat* vs. *describes cold* (see Table 7) because subjects reported that the adjective task used in Experiment 5 was subjectively very hard. Second, instead of noun-related distracters I now used spatially oriented animals (four animals looking to the right or to the left; see Figure 15). Noun-related distracters were not used in Experiment 6. In the noun task, animal distracters were always categorically congruent when the word was a moving object, and always categorically incongruent when the word was a non-moving object. Moreover, in both cases, half of the distracters were spatially congruent, the other half were spatially incongruent. Last, feedback was now only given after incorrect responses. In case of an error the word "Fehler!" (German for *error*) was displayed for 2000 ms (see Figure 16).

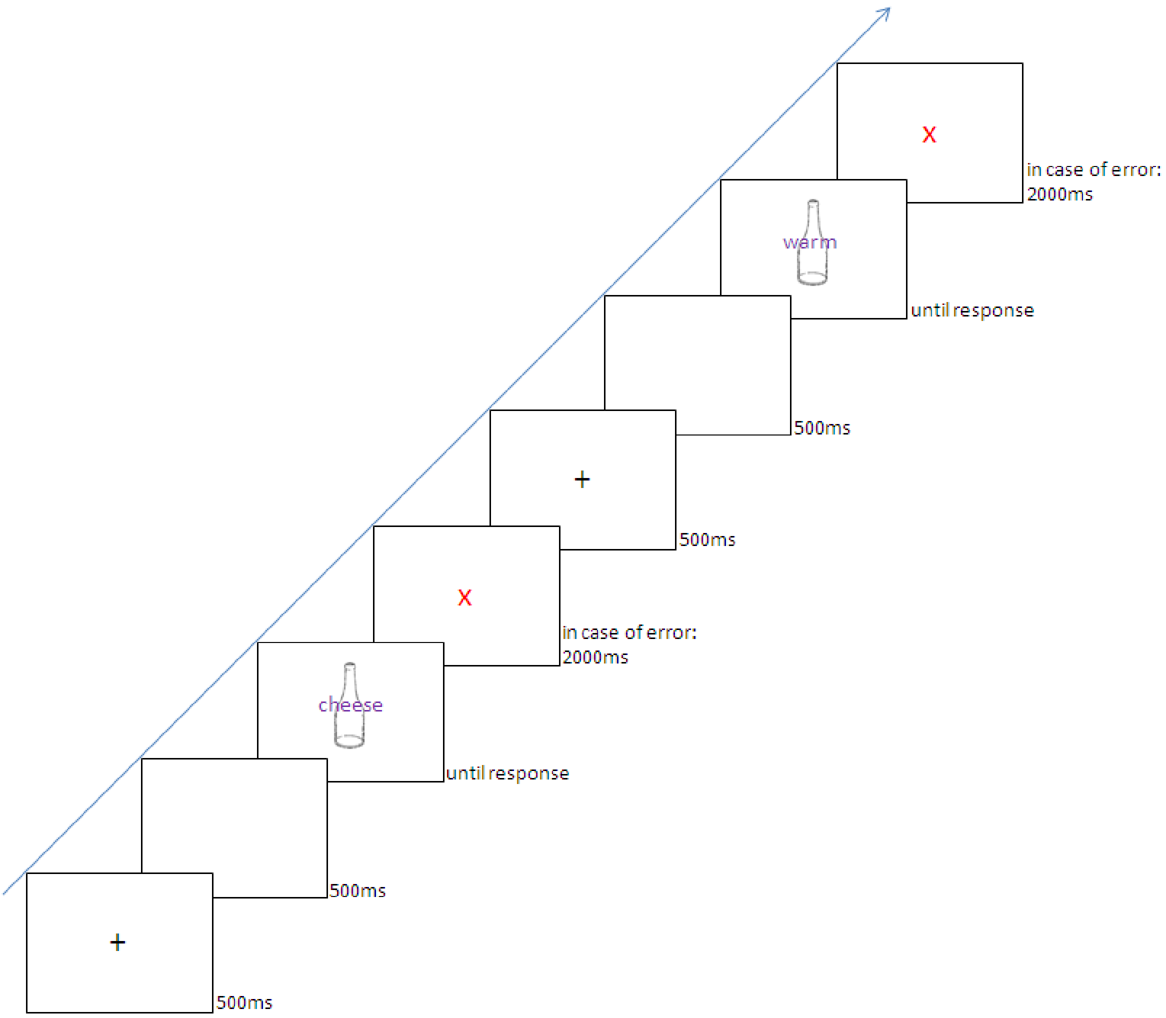

Figure 16. *Trial procedure in Experiment 6.*

DESIGN

A 2 (Task: nouns vs. adjectives) X 2 (Sequence: switch vs. repeat) X 2 (Distracter: noun vs. spatial) X 2 (Congruency: congruent vs. incongruent) repeated measures design was used.

RESULTS

One subject was excluded from all analyses due to keeping to forget the instructions and constantly asking questions throughout the Experiment. Results for the 2 (Task) X 2 (Sequence) X 2 (Distracter) X 2 (Congruency) ANOVAs are reported in Table 9 and depicted in Figure 17. Again, in the text, I will focus on RT results.

Table 9. *Results from the main ANOVAs conducted in Experiment 6. The overall ANOVA included the factors Task X Sequence X Distracter X Congruency. A separate ANOVA with the factors Sequence X Distracter X Congruency was conducted for the adjective task only. Significant results (p ≤ .05) are printed in bold.*

	RT (ms)						Error rates (%)					
	overall			adjective task			overall			adjective task		
Effect	**F**	**p**	**η^2**	**F**	**p**	**η^2**	**F**	**p**	**η^2**	**F**	**p**	**η^2**
Task	**10.04**	**< .01**	**.25**	-	-	-	< 1	.86	.00	-	-	-
Sequence	**23.50**	**< .01**	**.44**	**35.79**	**< .01**	**.54**	**5.20**	**.03**	**.15**	**6.83**	**.01**	**.19**
Distracter	**9.12**	**< .01**	**.23**	**9.18**	**< .01**	**.23**	3.89	.06	.12	< 1	.38	.03
Congruency	**6.77**	**.01**	**.18**	1.27	.27	.04	**16.40**	**< .01**	**.35**	**12.60**	**< .01**	**.30**
Task X Sequence	**19.68**	**< .01**	**.40**	-	-	-	**5.13**	**.03**	**.15**	-	-	-
Task X Distracter	< 1	.88	.00	-	-	-	1.00	.33	.03	-	-	-
Sequence X Distracter	1.75	.20	.06	< 1	.39	.03	< 1	.92	.00	< 1	.33	.03
Task X Sequence X Distracter	< 1	.66	.01	-	-	-	1.73	.20	.06	-	-	-
Task X Congruency	1.59	.22	.05	-	-	-	< 1	.34	.03	-	-	-
Sequence X Congruency	< 1	.86	.00	< 1	.77	.00	1.52	.23	.05	3.37	.08	.10
Task X Sequence X Congruency	< 1	.43	.02	-	-	-	< 1	.38	.03	-	-	-
Distracter X Congruency	**15.46**	**< .01**	**.34**	2.98	.09	.09	**19.80**	**< .01**	**.40**	**4.45**	**.04**	**.13**
Task X Distracter X Congruency	4.25	.05	.12	-	-	-	**6.59**	**.02**	**.18**	-	-	-
Sequence X Distracter X Congruency	**8.08**	**< .01**	**.21**	**6.26**	**.02**	**.17**	< 1	.80	.00	< 1	.50	.02
Task X Sequence X Distracter X Congruency	< 1	.81	.00	-	-	-	2.43	.13	.08	-	-	-

Like in Experiment 5, the four-way interaction was non-significant. However, the predictions only concerned the adjective task. Therefore, I conducted a second ANOVA for the adjective task only. The results are also displayed in Table 9. The interaction Sequence X Distracter X Congruency proved significant. Additional analyses revealed that on task repetitions only the main effect Distracter was significant, $F\,(1,30) = 11.34$, $\eta^2 = .28$. In contrast, on task switches to the adjective task the interaction Distracter X Congruency proved reliable, $F\,(1,30) = 7.29$, $\eta^2 = .20$. The congruency effect was significant for noun distracters, $t(30) = 2.3$, but not for animal distracters, $t(30) = .82$, $p = .42$.

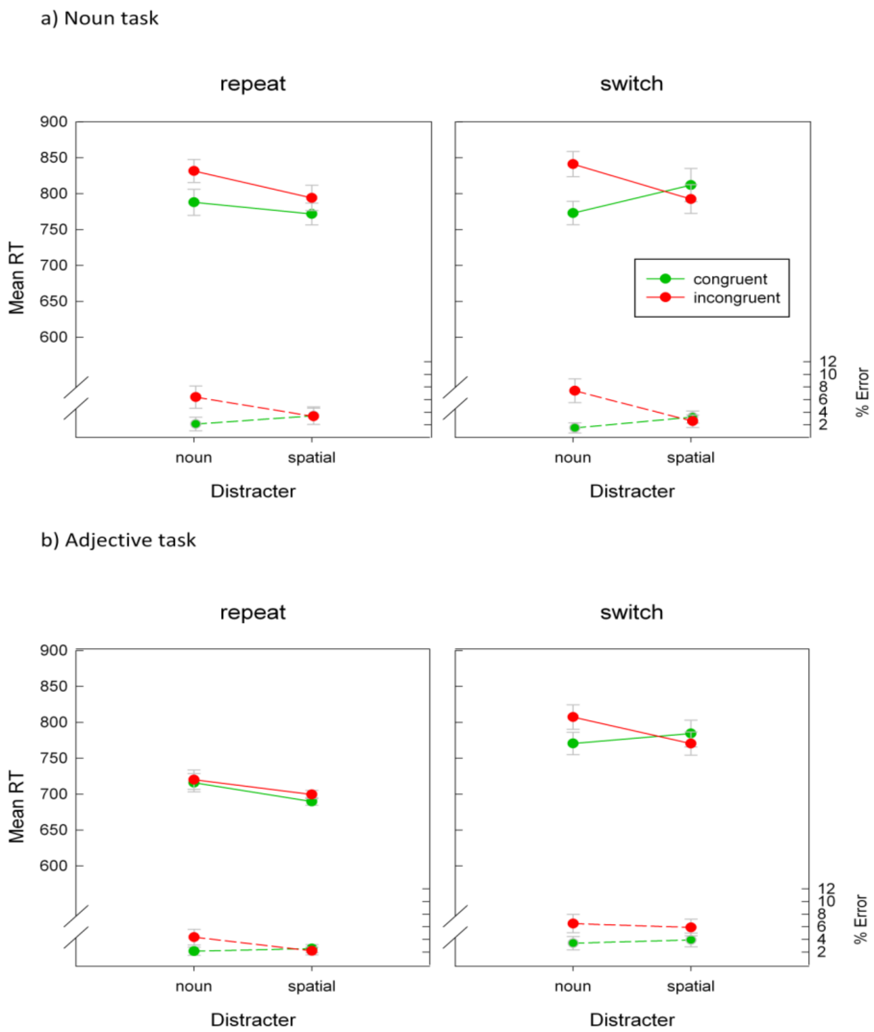

Figure 17. *Mean response times (RTs) in ms and error rates in % as a function of Task, Sequence, Distracter and Congruency in Experiment 6. Error bars represent inferential confidence intervals (Tryon, 2001) based on comparisons of congruent and incongruent trials.*

DISCUSSION

Experiment 6 replicated the results of Experiment 5 with respect to noun distracters. On task repetitions, shielding was intact and strong in the adjective task so that neither noun distracters nor spatial distracters interfered. Moreover, on switches to the adjective task there was a significant congruency effect for noun distracters. Again, this is attributed to a reduction of shielding because the shielding function typically prevents interference from irrelevant information. Importantly, spatial distracters did not interfere on task switches. This is taken as additional evidence for the shielding$_{ADV}$ account. A reduction in suppression of irrelevant information (shielding$_{SUP}$) should have resulted in interference by the spatially oriented animals. Instead, the fact that the animals were in no way related to the adjective task seems to have prevented any interference with the (also spatial) response. This is in line with the assumption that shielding is indeed an advantage for the processing of any information that is related to the task rule.

The results from the noun task are harder to interpret (but were not in the focus of our hypotheses in the first place). Spatial distracters were not only response-congruent or incongruent according to their spatial orientation, but also according to their belonging to the response-category *moving object*. In the ANOVA reported above, results were analyzed with respect to spatial congruency and did show effects on task repetitions. This seems to indicate that even an irrelevant feature has the potential to interfere if it is combined with a task-related feature (like with bivalent stimuli in TRCE studies). That is, the spatial orientation of the pictures might have interfered because the picture was task-related by way of its category-membership. However, the interpretation is speculative, since the experiment was not designed to dissociate between spatial and categorical congruency in the noun task.

CONCLUSIONS

I investigated two aspects of the shielding function of task sets in two experiments: the specific cognitive processes underlying the shielding function and the dynamics of the shielding function in the course of task switching. Subjects switched between categorizing nouns and categorizing adjectives, both of which were superimposed on distracter pictures. All distracters were related to the noun task in that they could be categorized according to the instructed rule *moving object* vs. *non-moving object*. Whether or not shielding was strong and effective on adjective task repetitions was assessed through the presence or absence of distracter interference. On noun task repetitions I did not expect shielding to prevent interference from the pictures because they had features that were related to the currently active task rule (see Part II). However, *shielding$_{SUP}$* and *shielding$_{ADV}$* made different predictions regarding interference from noun-related distracters on *switches* to the noun task. More specifically, shielding$_{\mathrm{SUP}}$ predicted increased interference on task switches because a reduction of shielding would mean less efficient suppression of distracting information. In contrast, according to shielding$_{\mathrm{ADV}}$, interference from noun-related distracters should be attenuated on task switches because the processing advantage for task-related information is not as strong as on task repetitions.

The main results can be summarized as follows: I replicated previous results showing that (1) distracters that are related to the currently relevant rule are automatically categorized (Part II of the present thesis) and (2) task shielding is reduced on task switches (Dreisbach & Wenke, 2011), as indexed by the interference of noun distracters on switches to the adjective task (and the lack thereof on repetitions). Noun-related distracters and spatial distracters did not interfere in the adjective task even when shielding was reduced. These results suggest that interference from noun distracters on switches to the adjective task worked by way of automatic retrieval of responses from memory (Mayr & Kliegl, 2000; Yamaguchi & Proctor, 2011) because such episodes did not exist for noun-related and spatial distracters.

In addition to replicating and extending previous findings, I gained more insight into the mechanisms underlying the proposed shielding function of task sets. First, I found that task shielding is powerful enough to prevent interference from distracters that are associated with a competing but currently inactive task. When shielding is intact on task repetitions, distracter pictures belonging to the response categories relevant for the noun task did not interfere in the adjective task. There, neither noun distracters nor noun-related distracters interfered, whereas on noun task repetitions all distracters resulted in significant congruency effects.

The second main result concerns the mechanism underlying the shielding function of task sets. When switching to the noun task, noun-related distracters interfered less than noun distracters, whereas on task repetitions, both kinds of distracter produced congruency effects (Experiment 1). In addition, even when shielding was reduced on switches to the adjective task, spatial distracters did not cause significant congruency effects. These results are taken as further evidence for the *shielding*$_{ADV}$ account. In the remainder of the discussion I will elaborate on these main findings.

Strength of shielding

I found no significant congruency effects on task repetitions in the adjective task. This is in sharp contrast to findings on the TRCE (e.g. Kessler & Meiran, 2010; Kiesel, Wendt, & Peters, 2007; Meiran & Kessler, 2008; Sudevan & Taylor, 1987; Waszak, Wenke, & Brass, 2008). Note that in task switching experiments with bivalent stimuli responses are typically faster when both features of a given target stimulus are associated with the same response in the two tasks, than when they are associated with different responses. Comparing the present results with studies on the TRCE illustrates how important the distinction between bivalent stimuli with distracting features and separate distracter stimuli is. When subjects switch between different features of the very same target stimulus, interference from information related to (and practiced in) the competing task results in response congruency effects. Here, with separate target and distracter stimuli this effect was reduced or even eliminated by task shielding. Distracters were automatically categorized in the noun task but no interference occurred in the adjective task. Note that I found no response-congruency effects but that I cannot rule out interference at a more abstract level of task set. Results from a study by Waszak, Wenke, and Brass (2008) suggest that stimulus features that are instructed but never practiced in a competing task still slow response times compared to a neutral condition (albeit they do not produce response congruency effects; but see also Liefooghe, Wenke, & De

Houwer, 2012; Waszak, Hommel, & Allport, 2003). Accordingly, noun and noun-related distracters alike would slow response times in the adjective task compared to a neutral condition without distracters (which was not included in the present experiments). In Experiment 5 I found no effect of Distracter in the adjective task. Although one might expect noun distracters to prime the noun task more strongly than noun-related distracters, overall response times for noun and noun-related distracters did not differ significantly. So, either both distracters primed the noun task to the same degree, or no interference at the level of task set took place. As was already mentioned above, the fact that switch costs were greater for the adjective task than for the noun task (irrespective of whether the adjective task was easier – as in Exp 6 – or harder – as in Exp 5 – than the noun task) suggests that all pictures might have primed the noun task, making switching to the adjective task harder or switching to the noun task easier, respectively. Moreover, in Experiment 6 the main effect of Distracter was significant. Responses were faster with spatial distracters than with noun distracters. This might also be taken as evidence for some task-level interference. However, the experiments were not designed to study interference at the level of task set.

The mechanism underlying the shielding function of task sets: support for the shielding$_{ADV}$ account

On switches to the noun task, noun-related distracters interfered less than noun distracters. This is important with respect to the two opposing hypotheses regarding the mechanism underlying the shielding function of task sets. Shielding$_{SUP}$ and shielding$_{ADV}$ make different predictions regarding the strength of interference from noun-related distracters on task switches. If a reduction of shielding was a reduction of distracter suppression as predicted by the shielding$_{SUP}$ account, one would have expected increased interference from all distracters because they should have been less efficiently suppressed. In contrast, shielding$_{ADV}$ predicted that a reduction of shielding would result in a reduction of the processing advantage for task-related information and – as a consequence – in reduced interference by noun-related distracters. Results clearly support the shielding$_{ADV}$ account that has been suggested before (Dreisbach & Wenke, 2011; Part II of the present thesis). Experiment 6 added even more evidence in favor of the shielding$_{ADV}$ account. On switches to the adjective task shielding was reduced but still no congruency effects for spatial distracters were found. The shielding$_{SUP}$ account would have predicted that attenuated suppression of interfering information should have resulted in a spatial congruency effect for animal distracters.

The interpretation of the results in terms of preferred target-processing is also related to results reported by Egner and Hirsch (2005). In an fMRI study with compound word-face Stroop stimuli they manipulated cognitive control sequentially and found that high control resulted in enhanced target processing rather than reduced distracter processing. I suggest that the use of a task rule results in a similar overall adjustment of settings that affect every trial in the experiment through enhanced processing of rule-relevant information. In other words, enhanced processing of task-related information helps prevent interference from task-unrelated information but – on the downside – increases the risk of interference by task-related (yet irrelevant) information. Given that in real life task-related information more often than not is also relevant, such a mechanism seems adaptive.

A final remark concerns the amount of switch costs in both experiments presented here. Significant switch costs were only found in the adjective task and were small or nonexistent in the noun task in both experiments (Experiment 5: –1 ms; Experiment 6: 8 ms). This might call into question whether subjects actually switched between tasks. Several reasons speak for task switching: First of all, although I acknowledge that subjective reports are not the most reliable of sources, in the post-experimental questionnaire only one subject reported having combined the two rules. This subject was excluded from all analyses. Second, the differential results for switch and repeat trials (e.g., the interaction Sequence X Distracter X Congruency in both experiments) are indicative of the presence of task switching. If subjects had not switched but instead had represented the rules as one single, superordinate task then interference in switch and repeat trials should not have differed. Third, switch costs were always significant in the adjective task (Experiment 1: 21 ms; Experiment 2: 77 ms). Interactions between switch and task type (smaller or no switch costs in one of the tasks) are not a rare finding in the task switching literature if results are reported separately for both tasks (e.g., Rogers & Monsell, 1995, Experiments 3, 4). Moreover, with univalent stimuli, small switch costs have been reported before. For instance, Wylie and Allport (2000, Experiment 1), found switch costs of only 20 ms, when subjects switched between naming the color of colored Xs and reading a color-word written in black. In the present experiments, the small switch cost to the noun task might be explained by the fact that the distracters were always related to the noun task and were presented on adjective task trials, too. They might have generally primed the noun task to a certain degree (e.g. Koch & Allport, 2006) and thereby might have reduced the switch cost. In sum, I am confident that subjects switched between tasks. In any case, the small switch costs do not call into question the interpretation in terms of intact and reduced shielding as the most plausible explanation for the results.

In the introduction to Part III I pointed out that that task activation most likely plays a crucial role in the shielding function. Assuming that task repetitions offer an activation advantage over task switches, the results so far support this view. Again, shielding was intact on task repetitions but reduced on task switches. Part IV served to further test the importance of task activation by looking into predictable switches, where task activation is presumably higher than on unexpected switches.

PART IV

SHIELDING IN THE CONTEXT OF PREDICTABLE TASK SWITCHING

INTRODUCTION

Switching between tasks is the rule rather than the exception. Oftentimes such switches are unexpected. Imagine sitting at the table with friends again (serving as an example so patiently in this thesis) concentrated, talking or playing a game of cards. You are able to rapidly switch tasks when there is a knock on the door or the telephone starts ringing, even if you had not anticipated this kind of interruption. At other times you might expect to be interrupted and know which task to attend to next but you might not know the exact time point of interruption. For instance, you might know that within the next half hour another friend will be arriving or at some point you will have to prepare more drinks. But only when seeing an empty glass would you know that you will now have to abandon your current task and refill it. In an experimental context, this resembles random task switching. Subjects know that they are expected to switch and are capable of remembering and applying all tasks, but they cannot fully prepare for a switch because task order is unpredictable. Only the appearance of a stimulus indicates which task to perform next. Previous results have shown that task shielding in these cases is only effective on task repetitions: You might not be affected by irrelevant groceries if you shop uninterruptedly (i.e. on task repetitions). But if you were to return to shopping after an interruption (say, meeting someone you know; i.e. a task switch), cheese or flour might temporarily distract you. But of course switching is not necessarily unpredictable. There are circumstances where you are able to prepare. By analogy, preparation also is possible in the task switching paradigm. The upcoming task can be indicated in advance by pre-cues (e.g. Meiran, 1996). Alternatively, task order can be fixed and therefore predictable (e.g. Rogers & Monsell, 1995). In both cases preparation of the upcoming task is possible to some degree.

From the task switching literature it is known that such preparation affects task performance in a beneficial way (see Part I of the present thesis). For instance, switch costs are often reduced when subjects are given time to prepare for the upcoming task. Yet, preparation effects are not necessarily switch specific. Even task repetitions can benefit from advance knowledge (e.g. Poljac et al., 2006; Rogers & Monsell, 1995). Therefore, preparation seems to positively affect task activation in general (Koch, 2005). This assumed activation advantage of prepared tasks (compared to tasks where preparation was not possible) was used in the present study to look into the effects of task activation on the shielding function. Findings from Dreisbach and Wenke (2011) as well as from shielding in the context of unpredictable task switching (Part III of the present thesis) suggest that rule activation plays a crucial role concerning the shielding function. Following this logic, if the shielding function is indeed reduced on task switches because it depends on task activation, performance on a prepared task switch should differ from performance on a random, unprepared switch (like in Experiments 5 and 6). That is, increased task activation on a prepared task switch should lead to shielding that is stronger than on an unexpected switch.

A popular method to enable preparation is the cued task switching paradigm, where a cue indicates the next task. This approach is mostly used with bivalent targets, which means that the cue is not only helpful but in fact necessary to determine which task to apply. With such cues the time between cue and stimulus-onset, the CSI, can be varied as a means of manipulating task activation (e.g. Koch & Allport, 2006). Another possibility is to cue the type of transition rather than the specific task (e.g. Schneider & Logan, 2007). Supposing that only two tasks are used, cuing subjects whether to expect a task repetition or a task switch is sufficient information to enable preparation of the correct task (the same does not hold true if more than two tasks are used and a switch is indicated). A third possibility to enable task preparation is to use predictable, alternating runs (e.g. Rogers & Monsell, 1995). Subjects know the order of tasks and can anticipate the next task correctly (e.g. AABBAA). This paradigm was chosen in the present experiment. The reason is that I wanted to keep the procedure as similar as possible to Experiments 5 and 6, since results will be discussed with respect to these supposedly unprepared conditions. I used univalent targets so cues were not necessary to determine the task. In addition, I opted for the alternating runs paradigm rather than cued task switching because the use of cues introduces the new element of cue encoding and processing, which sometimes is considered problematic for the interpretation of task switching results (see Logan & Bundesen, 2003). Last, it has been shown that cued task switching produces asymptotic performance effects after a switch, whereas a predictable sequence allows for full preparation on the first trial following a switch (Monsell, Sumner, & Waters, 2003; but see also Tornay & Milán, 2001). More precisely, with an unpredictable sequence, subjects seem to not fully commit to the task after a switch, most probably because they cannot foresee whether they have to switch back to the previous task on the following trial. Their performance gets asymptotically better (i.e. faster and less prone to interference) the more repetitions of the same task they get. In contrast, with the alternating runs paradigm, subjects know that after a switch the same task will be relevant for a given number of trials. Therefore, presumably they fully commit to the task on the first trial after a switch. Subsequent repetitions show no improvement in performance since the first repetition was supposedly already fully prepared. As a consequence, working with the alternating runs procedure allows predicting full task activation (i.e. intact shielding) on all repetition trials, whereas with the cueing procedure differences in shielding across more than one repetition would have to be taken into account.

EXPERIMENT 7

Experiment 7 served to learn more about the flexibility of the shielding mechanism, its cognitive origin, and the role of task activation. More specifically, I reasoned that shielding in terms of enhanced processing of task-related information should not be reduced on task switches if subjects knew which task to expect and prepare. If knowing which task to expect allows for intact task activation and shielding, interference from noun and noun-related distracters should be present on task switches in the noun task. Moreover, by the same logic, interference from noun distracters in the adjective task should be attenuated or absent even on task-switches. Therefore, in Experiment 7, the noun and adjective task were presented in alternating runs (AAAABBBB) so that shielding could be analyzed on predictable task switches. Always presenting four tasks in a row further allowed me to investigate interference over the course of more than one task repetition. However, given that with a predictable sequence commitment to the task very probably is already at its fullest on the first repetition (Monsell et al., 2003), no effect of position in run (i.e. 1st, 2nd, or 3rd repetition) was expected.

METHOD

PARTICIPANTS

Twenty-four students from the University of Regensburg (20 women, mean age = 22 years, age range: 18–33 years) participated for partial course credit. None of them had participated in Experiments 5 or 6. Participants had normal or corrected to normal vision. They signed informed consent and were debriefed after the session.

STIMULI AND PROCEDURE

Like in Experiments 5 and 6, 16 German nouns and eight adjectives served as target stimuli (see Table 7). Sixteen line drawings depicting the nouns served as distracters. The line drawings were taken from the Snodgrass collection (Csycowicz, Friedman, Rothstein, & Snodgrass, 1997; Snodgrass & Vanderwart, 1980). Target words were superimposed on distracter pictures. They were presented in size 18 Arial font and purple color. Compound stimuli appeared in the center of the screen against a white background.

Subjects again switched between a noun task and an adjective task. The tasks were presented in a fixed order (AAAABBBB etc.). If a noun appeared, it had to be categorized as a *moving* or a *non-moving object*. Adjectives had to be categorized as *describing heat* or *cold*. Subjects responded by pressing a left or a right response key on a standard QWERTZ-keyboard (“y”- and “m”-key). Category-response mappings were counterbalanced across subjects. Half of the distracter pictures depicted objects that were also used as target words in the noun task (noun distracters). The other half of the distracters depicted objects that never appeared as target words but still were related to the noun task inasmuch as they could be categorized as moving or non-moving objects (noun-related distracters). None of the distracters were related to the adjective task. Target and distracter could be response-congruent or incongruent, depending on the category they belonged to and the associated responses.

A trial started with a fixation cross (500 ms) followed by a blank screen (500 ms). Then the imperative word-picture compound stimulus appeared and remained on the screen until a response was given. In case of an error the word "Fehler!" (German for *error*) appeared on the screen for 2000 ms.

Subjects were informed about the tasks and the corresponding mappings via written instructions and saw a slide showing all 16 potential targets (eight nouns and eight adjectives). Both speed and accuracy were stressed. Before the Experiment proper, subjects completed two short single task blocks and one mixed task block for practice. In the single task blocks every target was presented twice in random order without any distracters, resulting in a block length of 16 trials per task. In the mixed task practice block, subjects predictably switched between the noun task and the adjective task. Half of the trials were task repetitions. In this mixed block target words were already superimposed on the distracter pictures. Every possible word-picture combination was shown once, resulting in 256 trials. Word repetitions, picture repetitions and negative priming trials were not allowed. Subjects were not specifically informed about the predictable order. Instead, it was assumed that they would (implicitly) pick up on the order during the practice block. The reason I opted for this approach is that I wanted to keep the paradigm as close as possible to Experiments 5 and 6. After the mixed practice block two experimental blocks with the same specifications followed.

DESIGN

A 2 (Task: nouns vs. adjectives) X 4 (Sequence: switch vs. 1st, 2nd, and 3rd repetition) X 2 (Distracter: noun vs. noun-related) X 2 (Congruency: congruent vs. incongruent) repeated measures design was used.

RESULTS

The following preprocessing procedure was applied: Only the two experimental blocks were analyzed. The first trial of a given block and trials where target and distracter depicted the same object were excluded from all analyses (3.5 %). Moreover, error trials and trials following an error were excluded from RT analysis (7.1 %). To correct for outliers, RTs exceeding two standard deviations from the individual cell mean were also excluded from RT analysis (5.5 %). I adopted a significance level of .05 in all analyses. Individual *p*-values for significant effects are not reported in the text.

RT DATA

First, I conducted a 2 (Task) X 3 (Repetition: 1st, 2nd, 3rd) X 2 (Distracter) X 2 (Congruency) repeated measures ANOVA, to check whether the first, second and third task repetition had a differential effect on any other factor. There was neither a main effect nor any significant interaction involving the factor Repetition, all $F < 2.1$, all $p > .14$, so data were collapsed over all repetition trials and a 2 (Task) x 2 (Sequence: switch vs. repeat) X 2 (Distracter) X 2 (Congruency) repeated measures ANOVA was conducted. Results are depicted in Figure 18 (see also Table 10). The main effects of Task, $F(1,23) = 10.92$, $\eta^2 = .32$, Sequence, $F(1,23) = 24.16$, $\eta^2 = .51$, and Congruency, $F(1,23) = 5.69$, $\eta^2 = .20$, were significant. Subjects were faster in the adjective task (702 ms vs. 757 ms). Repeat trials were again answered faster than switch trials (696 ms vs. 762 ms) and congruent trials were answered faster than incongruent trials (720 ms vs. 738 ms). The only significant interaction was between Task and Congruency, $F(1,23) = 19.97$, $\eta^2 = .47$. Additional analyses revealed that the congruency effect was significant in the noun task, $F(1,23) = 13.67$, $\eta^2 = .37$, but not in the adjective task, $F < 1$, $p > .68$. No other effects were significant, all $F < 2.7$, all $p > .11$.

ERROR DATA

Error data are also depicted in Figure 18 (see also Table 10). A 2 (Task) X 3 (Repetition) X 2 (Distracter) X 2 (Congruency) ANOVA revealed that again the factor Repetition did not result in a main effect or any significant interaction, all $F < 2.6$, all $p > .09$. Therefore, all repetition trials were collapsed and a 2 (Task) X 2 (Sequence) X 2 (Distracter) X 2 (Congruency) ANOVA was conducted. The main effect of Sequence was significant, $F(1,23) = 9.05$, $\eta^2 = .28$. Subjects made more errors on switch trials (4.8 %) than on repeat trials (2.8 %). The main effects of Distracter, $F(1,23) = 3.62$, $\eta^2 = .14$, $p = .07$, and Congruency, $F(1,23) = 3.08$, $\eta^2 = .12$, $p = .09$, were only marginally significant . However, Distracter interacted significantly with Congruency, $F(1,23) = 5.64$, $\eta^2 = .20$. There was a congruency effect for noun distracters, $F(1,23) = 4.91$, $\eta^2 = .18$, but not for noun-related distracters, $F < 1$, $p > .98$. No other effects were significant, all $F < 2.4$, all $p > .13$.

***Table* 10.** *Results from the main ANOVAs conducted in Experiment 7. An overall ANOVA included the factor Sequence. Separate ANOVAs were then conducted for repeat trials only and switch trials only. Significant results (p ≤ .05) are printed in bold.*

		overall			**repeat trials only**			**switch trials only**		
Effect		**F**	**p**	**η^2**	**F**	**p**	**η^2**	**F**	**p**	**η^2**
Task	RT (ms)	**10.92**	**< .01**	**.32**	2.74	.11	.11	38.58	< .001	.42
	Errors (%)	*< 1*	*.34*	*.04*	*< 1*	*.73*	*.01*	***4.80***	***.04***	***.17***
Sequence	RT (ms)	**24.16**	**< .001**	**.51**	-	-	-	-	-	-
	Errors (%)	***9.05***	***< .01***	***.28***	-	-	-	-	-	-
Distracter	RT (ms)	< 1	.35	.04	1.95	.18	.08	< 1	.52	.02
	Errors (%)	*3.62*	*.07*	*.14*	*2.92*	*.10*	*.11*	*< 1*	*.70*	*.01*
Congruency	RT (ms)	**5.69**	**.03**	**.20**	1.53	.23	.06	**16.53**	**< .001**	**.42**
	Errors (%)	*3.08*	*.09*	*.12*	*1.35*	*.26*	*.06*	***5.15***	***.03***	***.18***
Task X Sequence	RT (ms)	1.37	.25	.06	-	-	-	-	-	-
	Errors (%)	*< 1*	*.63*	*.01*	-	-	-	-	-	-
Task X Distracter	RT (ms)	< 1	.66	.01	< 1	.52	.02	< 1	.75	.01
	Errors (%)	*< 1*	*.38*	*.03*	*1.49*	*.24*	*.06*	*< 1*	*.86*	*.00*
Sequence X Distracter	RT (ms)	2.11	.16	.08	-	-	-	-	-	-
	Errors (%)	*1.72*	*.20*	*.07*	-	-	-	-	-	-
Task X Sequence X Distracter	RT (ms)	< 1	.51	.02	-	-	-	-	-	-
	Errors (%)	*1.09*	*.31*	*.05*	-	-	-	-	-	-
Task X Congruency	RT (ms)	**19.97**	**< .001**	**.47**	**10.56**	**< .01**	**.32**	**8.89**	**< .01**	**.28**
	Errors (%)	*2.31*	*.14*	*.09*	*3.59*	*.12*	*.10*	*< 1*	*.49*	*.02*
Sequence X Congruency	RT (ms)	< 1	.84	.00	-	-	-	-	-	-
	Errors (%)	*< 1*	*.89*	*.00*	-	-	-	-	-	-
Task X Sequence X Congruency	RT (ms)	2.69	.11	.11	-	-	-	-	-	-
	Errors (%)	*2.16*	*.16*	*.09*	-	-	-	-	-	-
Distracter X Congruency	RT (ms)	< 1	.63	.01	< 1	.66	.01	**10.04**	**< .01**	**.30**
	Errors (%)	***5.64***	***.03***	***.20***	*2.86*	*.11*	*.11*	*3.73*	*.07*	*.14*
Task X Distracter X Congruency	RT (ms)	< 1	.52	.02	< 1	.82	.00	1.68	.21	.07
	Errors (%)	*< 1*	*.84*	*.00*	*< 1*	*.83*	*.00*	*< 1*	*.99*	*.00*
Sequence X Distracter X Congruency	RT (ms)	1.74	.20	.07	-	-	-	-	-	-
	Errors (%)	*< 1*	*.41*	*.03*	-	-	-	-	-	-
Task X Sequence X Distracter X Congruency	RT (ms)	< 1	.86	.00	-	-	-	-	-	-
	Errors (%)	*< 1*	*.86*	*.00*	-	-	-	-	-	-

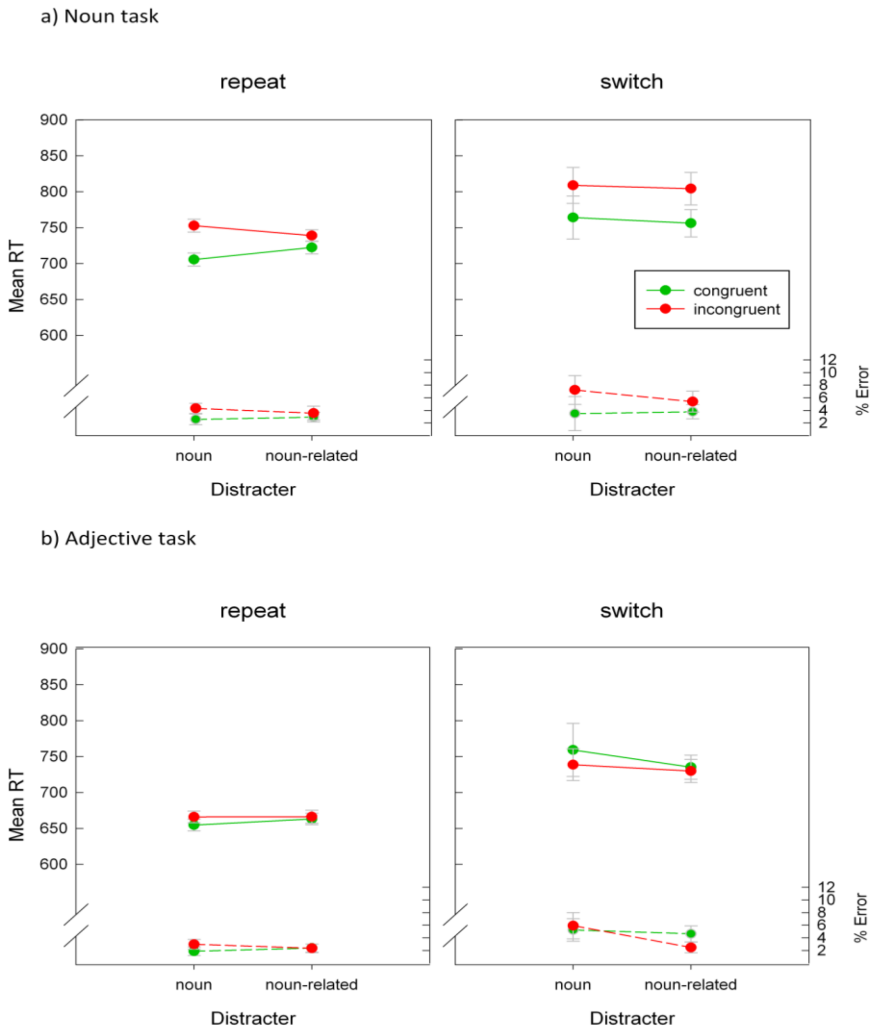

***Figure 18**. Mean response times (RTs) in ms and error rates in % as a function of Task, Sequence, Distracter and Congruency in Experiment 5. Error bars represent inferential confidence intervals (Tryon, 2001) based on comparisons of congruent and incongruent trials.*

Discussion

The discussion of the results will focus on RT data. Errors were few and did not counteract RT results. Moreover, results will be discussed with respect to switches and repetitions in general. They were not affected by whether subjects repeated the task for the first, second, or third time. This fits well with results from Monsell et al. (2003), who found that with a predictable task sequence full preparation is reached on the first trial following a switch. In contrast, with random switching these authors found a decrease in RT following more than one repetition after a switch. This was attributed to the fact that with alternating runs subjects' commitment to the task is complete after a switch because they know how many repetitions will follow. In contrast, such knowledge is impossible with random switching. A switch back to the just abandoned task is just as likely as a repetition. Therefore, commitment to the task only gradually increases with the number of repetitions.

One might argue that the alternating runs paradigm was not the most suitable approach to a manipulation of task activation. Activation is more commonly manipulated by prolonging the CSI (e.g. Koch & Allport, 2006): A long interval between cue and task presumably allows subjects to prepare the upcoming task more fully than a short CSI. Introducing alternating runs might seem like a rather conservative manipulation since subjects might not pick up on the sequence (remember that they were not explicitly told about the AAAABBBB sequence). However, first and foremost, results indicate that the manipulation was effective. In Experiment 7 I obtained results different from those of Part III, where task order had been random. More precisely, task sequence affected distractibility in Experiments 5 and 6, but had no impact on the pattern of interference in Experiment 7. In addition, as already stated above, the use of cues might have led to a gradual increase of task activation over the course of more than one repetition (Monsell et al., 2003). This additional factor would have complicated an already elaborate 4-factorial design.

In Experiment 7 I found the typical switch cost but no interaction between Sequence and any other factor. With a predictable task order, switches and repetitions showed the same pattern of interference: All of the distracters interfered in the noun task and no significant interference was found in the adjective task. So, in accordance with the hypothesis, shielding was not reduced on switch trials if subjects knew the upcoming task. Interference from noun distracters and noun-related distracters was not affected by whether the task switched or repeated. This is in sharp contrast to Experiments 5 and 6, where task sequence interacted with distracter congruency. More precisely, in Experiment 5, the pattern of results indicated that shielding was reduced on task switches because interference by noun-related distracters was attenuated. Here, there was no indication of a reduction of shielding. Hence, the predictability of the task order presumably made it possible to enable full task activation on task switches. As a consequence, shielding for the upcoming task was intact on a task shift. In the adjective task the chance to prepare (and hence intact shielding on switch trials) resulted in performance that was not affected by distracters related to the noun task. Neither noun nor noun-related distracters interfered on task switches and on task repetitions. In contrast, in Experiments 5 and 6 noun distracters had interfered on switches to the adjective task.

In sum, the results can be interpreted as follows: Preparation enables enough task activation for intact shielding even on switch trials. Both task repetitions and task switches are characterized by preferred processing of information that is related to the currently relevant task. Preparation thus prevents interference from the currently irrelevant task, even on a switch.

I explained the difference in results between Experiments 5 and 6, and Experiment 7 in terms of task activation and relaxed vs. fully active shielding. In Experiments 5 and 6, shielding was presumably relaxed on task switches, whereas Experiment 7 allowed for the preparation of the upcoming task and therefore offered the possibility of full shielding even on task switches. However, there is a potential alternative explanation for the different patterns of interference found for noun-related distracters in the adjective task. Hübner, Dreisbach, Haider, and Kluwe (2003) found that when subjects switched between three tasks interference from a recently abandoned task was reduced compared to interference from a task that had been abandoned less recently (see also Kuhns, Lien, & Ruthruff, 2007; Li & Dupuis, 2008). More precisely, flanker interference in trial N was reduced when the flankers were associated with the task executed in trial N-1 compared to interference from flankers from a task that had been executed in trial N-2 or earlier. Hübner et al. attributed this reduction of interference to backward inhibition of the preceding task set (Mayr & Keele, 2000). However, like the classical n-2 repetition costs reported by Mayr and Keele, the reduction of interference was only found for predictable tasks (by way of pre-cues or predictable task order). Along the lines of Hübner and colleagues, one could explain the current results of Part III and Part IV in terms of backward inhibition, too. In Experiments 5 and 6, where task order was random the noun task was not inhibited after its execution because subjects did not know which task to expect next. Accordingly, on task switches to the adjective task SR mappings from the noun task were still active enough to interfere. In contrast, in Experiment 7 the noun task could be inhibited because subjects knew that the adjective task would follow. As a consequence, interference from the inhibited noun task was non-significant in the adjective task. Although I cannot and do not want to rule out that inhibition contributed to the results, I do not think that it is the sole reason for the different results of Experiments 5 and 6, and Experiment 7. Although in the study of Hübner and colleagues interference from the competing task was reduced by inhibition it was still significant, whereas congruency effects in the present study completely disappeared on predictable task switches. Note though that Hübner et al. investigated task interference, not response-congruency effects. Moreover, an inhibitory account might partly explain the results in the adjective task, but it cannot account for the differential results obtained in the noun task of Experiments 5 - 7. Inhibition of the adjective task is unlikely to have affected interference from noun-related distracters in the noun task. Still, interference was attenuated on switches to the noun task when task order was random. I therefore conclude that although backward inhibition may have contributed to the results, the entire data pattern of Experiments 5 - 7 can hardly be explained without the assumption of relaxed shielding in Experiments 5 and 6, and intact shielding in Experiment 7.

PART V

GENERAL DISCUSSION

SUMMARY OF THE CURRENT FINDINGS

The present thesis addressed questions concerning the shielding function of task sets first described by Dreisbach and Haider (2008, 2009). This shielding function is a consequence of rule use, more specifically the application of categorization rules. It is a mechanism that allows one to attend to relevant information by reducing the impact of distraction on target processing. Put differently, applying categorization rules instead of SR mappings enables the system to discard irrelevant information and focus on features that are important to the task at hand. This can be seen, for instance, in reduced distracter interference in subjects using task sets (as opposed to arbitrary mappings). More specifically, studies by Dreisbach and Haider (2008, 2009) were the first to show that subjects applying categorization rules are not affected by spatially oriented distracters or changes in an irrelevant target feature such as color or font. In contrast, subjects using SR mappings showed binding effects between irrelevant target features and the response as well as congruency effects for spatially oriented animal distracters. In 2011, Dreisbach and Wenke extended findings on the shielding function by showing that shielding is fully intact on task repetitions but relaxed on task switches.

The present thesis addressed specific aspects of the shielding function of task sets, especially with respect to the underlying mechanism. Table 11 lists the aforementioned results of previous studies and offers an overview of the findings reported in this thesis.

Table 11. *Summary of the results of the early and current studies on the shielding function of task sets.*

Study	Paradigm	Task rule(s)	Distraction	Results and Interpretation
Dreisbach, Goschke, and Haider (2007)	early information TS vs. late information TS vs. SR	red stimulus consonant/vowel green stimulus animal/no animal	Target color	Interaction Information condition X Block X Task type: Early information condition: switch costs from the beginning (Block 1) Late information condition: switch costs after mention of the rules (Block 5) SR condition: no switch costs Task rules – once they are known – are preferred over the use of SR mappings, even though they result in switch costs.

<table>
<tr><th>Study</th><th>Paradigm</th><th>Task rule(s)</th><th>Distraction</th><th>Results and Interpretation</th></tr>
<tr><td>Dreisbach and Haider (2008)</td><td>SR vs. 1TS vs. 2TS</td><td>1 TS
Moving/non-moving

2TS
red stimulus
consonant/vowel

green stimulus
animal/no animal</td><td>Target color</td><td>SR condition: Interaction Color X Response

2TS condition: Interaction Color X Response

1TS condition: no interaction Color X Response
____
Binding between color and response happens only in the SR condition. The use of a single task rule shields against the irrelevant stimulus feature color.</td></tr>
<tr><td>Dreisbach and Haider (2009)</td><td>SR vs. 1TS</td><td>covering part of the leg/not covering the leg</td><td>Line drawings (related distracters and spatially oriented animals)</td><td>SR condition: Congruency effects for related and spatial distracters

1TS condition: Congruency effects only for related distracters.
____
Task rules shield against the irrelevant spatial orientation of distracters.</td></tr>
<tr><td>Dreisbach and Wenke (2011)</td><td>Task switching</td><td>Numeral
odd/even

Letter
Consonant/vowel</td><td>Target color or Target font</td><td>Task switches: Interaction Color/Font X Response

Task repetitions: No interaction Color/Font X Response
____
Shielding is intact on task repetitions, but relaxed on task switches.</td></tr>
<tr><td colspan="5">↑↑↑ Studies conducted before the present thesis ↑↑↑</td></tr>
<tr><td colspan="5">↓↓↓ Studies conducted for the present thesis ↓↓↓</td></tr>
<tr><td colspan="5">Summary Part II
When subjects use a rule, task-related distracters are automatically categorized accordingly.
This indicates that the mechanism underlying shielding is enhanced processing of task-related information.</td></tr>
<tr><td>Part II
Experiment 1</td><td>1TS</td><td>odd/even</td><td>Arabic numerals (target-related and task-related)</td><td>Congruency effects for target-related and task-related distracters
____
Task-related distracters are automatically categorized according to the rule.</td></tr>
</table>

Study	Paradigm	Task rule(s)	Distraction	Results and Interpretation
Part II Experiment 2	SR vs. 1TS	moving/non-moving	Line drawings (target-related and task-related)	1TS condition : congruency effects for target-related and task-related distracters SR condition : congruency effect for target-related distracters only ═══ Task-related distracters are automatically categorized according to the rule. Stimulus-specific effects can be excluded as the source of interference.
Part II Experiment 3	1TS	moving/non-moving	Line drawings (target-related and task-related)	Congruency effects for target-related and task-related distracters ═══ Task-related distracters are automatically categorized according to the rule, even if they are not expected as future targets.
Part II Experiment 4	1TS	moving/non-moving	Line drawings (task-related only)	Congruency effect for task-related distracters ═══ Task-related distracters are automatically categorized according to the rule, but this categorization is not strategic.
Summary Part III When shielding is relaxed, interference by task-related information is attenuated. This is taken as evidence, that the mechanism underlying the shielding function relies on preferred processing of task-related information.				
Part III Experiment 5	Random task switching	Noun task moving/non-moving Adjective task wine/music	Line drawings (noun and noun-related)	Task repetitions Interaction Task X Congruency: Congruency effect in the noun task, but not in the adjective task Task switches Interaction Distracter X Congruency: Congruency effects in both tasks for noun distracters, but not for noun-related distracters ═══ When shielding is fully active (task repetitions), information related to the current task interferes, whereas information from the competing task does not interfere. When shielding is relaxed (task switches), interference from task-related information is reduced, while at the same time SR mappings from the competing task can interfere.

Study	Paradigm	Task rule(s)	Distraction	Results and Interpretation
Part III Experiment 6	Random task switching	Noun task moving/non-moving Adjective task hot/cold	Line drawings (noun and spatial)	**Adjective task** Interaction Sequence X Distracter X Congruency: Noun distracters interfere on task switches only, spatial distracters never interfere When shielding is fully active, information related to the competing task and spatially oriented animals do not interfere. When shielding is relaxed, SR mappings from the competing task interfere, whereas the spatially orientation animals still do not (presumably because it is not related to any of the tasks and therefore not preferentially processed)
Summary Part IV Task activation plays a crucial role for the shielding function. When a switch is predictable, shielding is not relaxed.				
Part IV Experiment 7	Predictable task switching: AAAABBBB	Noun task moving/non-moving Adjective task hot/cold	Line drawings (noun and noun-related)	Noun task: overall congruency effect Adjective task: no congruency effect No effect of Sequence The shielding function of task sets depends on task activation. With full preparation, task-shielding is not relaxed on task switches.

SHIELDING AND TASK-RELATED DISTRACTERS

All experiments presented in this thesis were designed to uncover the processes serving the shielding function of task sets. They unequivocally show that the use of rules enhances the processing of relevant features, that is, the discriminative characteristic (i.e. category membership) that determines the response.

The first part of the present work addressed the effect of the shielding function in the presence of task-related distracters. In Experiments 1-4 I could show that distracter pictures that can be categorized according to the current rule interfere with target-processing. The congruency effect I observed for distracters that were related to the task is a first indication that shielding reflects a preference for features that are related to the instructions insofar as they determine the response. In the artificial setup of an experimental paradigm the observed effect might be considered unnecessary or disruptive. Yet, it shows that when subjects are instructed to use a rule, they do. Although the correct response is determined in most trials (meaning that subjects are very well able to discriminate between targets and distracters) rule application affects all stimuli, thereby resulting in congruency effects. This rigorous rule use is certainly adaptive in a non-experimental environment. Real life situations in which information is task-related but nevertheless irrelevant seem far more unlikely than the opposite case: If something fits a category, criterion, or rule, it more often than not is worth further examination.

In sum, Part II brought up evidence that the shielding function is not an indiscriminating inhibitory mechanism. Instead of suppressing anything that is not a target (which would seem a rather effortful way of shielding) a preference for related features allows the system to be susceptible to potentially relevant information. Put differently, what kind of information gets access to the response system or not critically depends on the categories regarded as relevant by the instruction. Information that falls within those categories is automatically processed and classified, and – in the paradigm employed here – results in the congruency effects that indicate preferential treatment of task-related information. The effect of this (involuntary) categorization of distracter stimuli was significant even in the first block. Therefore, it does not seem to depend on excessive rule practice. However, I cannot rule out that at least some trials of rule application are required. Looking at the first block only still comprised more than 100 trials in Experiments 1 - 4. Therefore, a gradual increase of the effect over the first few trials is possible. Considering that the rule *moving object* vs. *non-moving object* was chosen because it was most probably new to subjects it even seems reasonable to assume that a few practice trials might have been necessary. In contrast, with natural categorization rules such as *odd/even* (Experiment 1) shielding might be strong from the very beginning. Yet, overall, the effect of practice on the shielding function was not the subject of interest in the present thesis, and it seems negligible when more than 100 trials are considered (which is usually the case). Interestingly, on a side note, the lack of shielding in subjects using SR mappings can be prevented by practice. Dreisbach and Haider (2009) found that spatial congruency effects could be diminished in the SR group if practice trials before the experiment proper did not involve distracting pictures. That is, if subjects were able to practice the relevant SR mappings without any interfering spatial information their performance on subsequent experimental trials was not affected by the animal distracters. This result will be addressed again later.

SHIELDING IN A SWITCHING CONTEXT

Part III and Part IV offer an appealing explanation regarding the shielding function of task sets. They brought up evidence that the shielding function is served by advantages in processing for task-related information and that it critically depends on the degree of task activation.

Experiments 5 and 6 directly showed that the mechanism underlying the shielding function is preferential processing of task-related information rather than inhibition of irrelevant distraction. This mainly can be inferred from the attenuated congruency effects for task-related distracters on task switches. If a relaxation of shielding meant a relaxation of inhibition then interference should be increased on task switches. Instead, I found that task-related distracters interfered less on switch trials when shielding was relaxed. This indicates that fully intact shielding usually reflects a processing advantage for task-related features. Of course I cannot rule out that inhibition added to the effect. But the shielding function seems to be primarily supported by prioritized processing of task-related material, although irrelevant information most likely is also processed to a certain degree. As Dreisbach and Wenke (2011) already pointed out, binding effects on switch trials could not occur if target color/font had not been processed on the preceding trial. However, access to the response system seems to be granted only to relevant information which is (not necessarily consciously) determined through the instructed categories. As a consquence, distracters are also considered during response selection if they match the instructed categories and therefore affect response times.

The second conclusion that can be drawn from Parts III and IV is that shielding depends on task activation, i.e. the degree of activation of the relevant and/or the irrelevant mappings. Task activation is typically assumed to be lower on a switch trial than on a repetition trial (e.g. Allport et al., 1994; for a review see Vandierendonck et al., 2010). This activation advantage presumably led to the difference in results for switch and repeat trials in Experiments 5 and 6. Full task activation on a repetition enabled intact shielding, whereas the shielding function was relaxed on task switches (see also Dreisbach & Wenke, 2011). Experiment 7 offered more compelling evidence for the involvement of task activation in the shielding function. When task activation on switch trials was manipulated by allowing subjects to prepare the upcoming task through the use of a predictable sequence, switch and repeat trials did not differ regarding the pattern of interference. Although mechanisms other than shielding (e.g. inhibition of the previous task set, see Discussion of Experiment 7) might have contributed to this result, overall in my opinion an activation-dependent shielding mechanism offers the best explanation.

One particular aspect of the results specific to Experiment 6 has not been discussed so far. The spatial animal distracters that interfered in the SR group of Dreisbach and Haider (2009) did not interfere on switches to the adjective task in Experiment 6. This result suggests that even with a relaxation of shielding on a task switch performance with a task set in the face of distraction is still not at the level of (easily disrupted) performance with SR mappings. In contrast to Dreisbach and Haider's SR group where spatial congruency effects occurred, no such effect was found on switches to the adjective task in Experiment 6 of the present thesis. Consequently, the relaxation of shielding does not necessarily mean susceptibility to disruption in general. The spatial orientation of the animals was not related to any of the tasks that could have been activated on a switch trial (i.e. residual activation of the previous task and activation of the current task) and should therefore not be expected to interfere. In fact, so far interference on task switches always has been linked to the competing task in one way or the other. In Part III and Part IV of the present thesis the distracters were related to the noun task, whereas in the study by Dreisbach and Wenke (2011) the irrelevant feature may have been linked to the competing task on a switch trial. Therefore, the conclusion that the relaxation of shielding is merely a consequence of *relevant* task activation must be amended by the assumption that *irrelevant* task activation (i.e. task set inertia; Allport et al., 1994) might also contribute. Interference by noun distracters on task switches in Experiments 5 and 6 could be due to both weaker activation of the relevant task, as well as residual activation of the irrelevant task. Likewise, the lack of interference in Experiment 7 might be caused by the already strong activation of the current task and by the inhibition of activation of the preceding task. Yet, it was already stated in the Discussion of Experiment 7 that an account *solely* based on inhibition is unsuited to explain all the results of Experiments 5 -7 (e.g. interference in the noun task).

The notion that relaxed shielding is not increased susceptibility to interference in general fits well with recent results from Wendt, Kiesel, Mathew, Luna-Rodriguez, and Jacobsen (2013). The authors found that task sequence (i.e. repetition vs. switch) modulated interference that was due to between-task competition. However, an effect unrelated to both tasks was not modulated by the type of transition. Between-task interference was stronger on task switches, whereas the magnitude of the SNARC effect (spatial-numerical association of response codes; Dehaene, Bossini, & Giraux, 1993) was not affected by the type of transition. Wendt et al. concluded that task switches do not lead to an overall increased distractibility because this should have resulted in an increased SNARC effect, too. Instead, they proposed that proactive interference from the preceding task is greater on task switches, resulting in increased susceptibility merely to competing mappings but not to irrelevant information in general. Yet, even if one is to assume that – contrary to what Wendt et al. proposed – reduced shielding does not result in a greater susceptibility to all kinds of distracters, one aspect of the study still seems to be at odds with the idea of a shielding mechanism: the SNARC effect was not only reliable on task switches, but also on task repetitions. The presence of this effect might be taken as evidence against a shielding function because the subjects had used categorization rules. However, in contrast to binding effects or spatial congruency effects evoked by animals, the SNARC effect is a basic and strong source of interference. With another well known effect, namely the Simon effect, shielding has been found to *not* prevent interference before (Metzker & Dreisbach, 2009, 2011). It seems that the shielding function is not a global, unrelenting mechanism that prevents just any distraction from interfering with performance. Instead, whether categorization rules are useful in the face distraction seems to depend on the paradigm and must be established separately for different distracting features, qualities or setups. This constraint seems adaptive, since rule use should certainly benefit performance but not at the cost of complete and utter rigidity. Taken an example to the extremes, sorting their fruit by color might keep a caveman from getting distracted by their shape, but an orienting reaction to an approaching snake might still be in order. Categorizing helps shield from distraction to a certain degree. However, when the strength of interference exceeds a certain (to be established) point or, the shielding mechanism can be overcome.

THE MECHANISM UNDERLYING THE SHIELDING FUNCTION

So far, it has been established that the effect of the shielding function on unrelated and task-related distracters differs. Moreover, shielding most probably relies on enhanced target processing and depends on task activation. In that respect, shielding works in favor of the stability of behavior when it comes to cognitive control. At the same time, flexibility in general does not seem to be greatly impaired. But what exact processes might underlie this shielding function and the suggested processing advantage for task-related information? Remember that task rules differ from single SR rules in that they provide subjects with a common response-defining stimulus feature, for instance category membership. That is, task rules create an association between that category/defining feature and the response.

The advantage in processing might then simply be allocation of attention to the relevant feature. With regard to simple visual features, Folk, Remington, and Johnston (1992) suggested that spatial attention is involuntarily allocated to features that are critical to performance of the target task (but see Gronau, Cohen, & Ben-Shakhar, 2009). They used onset cues (prior to the target, a cue appears at one of four possible locations) and color cues (prior to the target, cues appear at all four locations, but one differs in color), and combined these with an onset task (i.e. judging at which of the four locations a stimulus appears) and a color task (i.e. at which location does the stimulus appear in a different color). Results showed that a cue validity effect (i.e. better performance on correctly cued trials than on incorrectly cued trials) was reliable only when the cue shared the feature property of the target task. More precisely, onset cues resulted in a cue validity effect in the onset task, but not the color task. On the other hand, a cue validity effect for color cues was only found in the color task. Folk et al. (1992) suggested that exogenous orientation of spatial attention is contingent on the relationship between features of the cue and features critical to the target task.

This means that attentional control settings can be set in accordance with task demands. If one were to extend this *contingent involuntary orienting* account to semantic information, shielding might simply be an attentional bias. If task-related features capture attention, they might gain access to the response system more easily. This preference might be realized in computational models such as the Executive Control of Visual Attention (ECTVA) theory by Logan and Gordon (2001), where a bias toward specific response categories is implemented. In fact, in 2009, Dreisbach and Haider had already suggested that applying rules might guide attention towards relevant aspects or features – for instance by simply reducing information – and thus result in attenuated vulnerability to distraction. One problem with this account is the bold step from spatial attention to static (e.g. color) or dynamic (e.g. sudden onset) discontinuities suggested by Folk et al. to the attentional selection of semantic categories required in the shielding function. In addition, Gronau et al. (2009) claim that task-related interference is not accompanied by attentional capture of the distracting stimuli. They used the personal significance effect (i.e. slowed response times when a personally significant word like the subject's own name is presented inside the focus of attention) to assess whether distracting stimuli capture attention. Subjects had to name the color of rectangle presented in the centre of the screen. A colored word denoting either a personally significant or a neutral meaning served as the distracter. When this distracter was presented within the focus of attention (i.e. within the colored rectangle) both the color congruency effect and the personal significance effect were significant but they did not interact. In contrast, when the distracter was presented outside the focus of attention (i.e. above or below the rectangle) only a color congruency effect was found. The authors took this result as an indication that the interfering qualities of task-related stimuli are not accompanied by attentional capture. If the distracter outside the focus of attention had capture attention, a personal significance effect should have occurred. Another problematic result for an attentional account comes from a study by Hommel (2005). He found that attention does not seem to be necessary for the formation of event files. Consequently, explaining shielding by proposing an attentional bias *against* irrelevant information such as target color would not explain the lack of binding effects reported by Dreisbach and Haider (assuming, of course, that binding effects are caused by event files). Overall, although a distinction must be drawn between attentional capture and an attentional bias or selective attention in general, a purely attentional account of shielding would certainly prove problematic.

An alternative explanation of the shielding function of task sets is based on the strength of activation of response category representations. Meiran and Kessler (2008; Kessler & Meiran, 2010) suggested that the TRCE is not caused by the representation of task rules in working memory (WM) because WM load does not affect the TRCE. Instead, they proposed that representations of well established response categories in activated LTM (Cowan, 1988; Oberauer, 2001) are the reason for such congruency effects. They backed their hypothesis with the finding that a TRCE only appeared with familiar response categories but not with novel response representations. More specifically, in a 2 x 2 grid a TRCE was found when the response categories up/down or left/right relative to the dissecting lines of the grid were used. However, when the grid was rotated by an angle of 45°, the locations relative to the dissecting lines could no longer be represented as up/down and left/right. In that case, a TRCE did not occur (see Part I). Along the lines of Meiran and Kessler, one could assume that with a binary categorization rule response categories are more strongly activated in LTM and hence more accessible than with eight individual SR mappings. This accessibility, in turn, might promote categorization according to the rule and reduce interference. This explanation would presume that the number of response categories activated in LTM is inversely related to the activation of said categories: the more response categories there are, the weaker each of them is activated.

I prefer a third, slightly different explanation that focuses on associative strength rather than the strength of response representations only. When subjects use a binary categorization rule the mapping is biunique. One category is mapped to one response and the other category is mapped to the other response. Conversely, each response is associated with a single category only (one-to-one mapping). Irrespective of how many different exemplars are used in the task, the association with the response is established via the category (see Figure 1). In contrast, when subjects use two response keys but more than two SR mappings these mappings are not biunique. Instead, several separate stimuli are mapped to one response (many-to-one mapping). Without a mediating category many different targets elicit the same response and each response is associated with more than one stimulus (see also Metzker & Dreisbach, 2009; 2011). I assume that the one-to-one mapping results in a strong association between a category (e.g. *moving object*) and a response (e.g. *left*). This strength allows efficient response selection that simply overpowers interference by irrelevant distracters.

The interpretation of shielding in terms of strong associations between categories and responses would fit well with the notion that shielding is dependent on task activation. That is, if a task is not fully activated (e.g. on an unexpected switch trial, then shielding is also reduced because the associations between target categories and responses are not fully activated. Then, one might conclude that on task switches – where task activation and therefore shielding is relaxed – stimulus-specific interference effects can more easily occur because they compete with associations that are not as strongly activated as on task repetitions. On the other hand, on task repetitions task shielding prevents stimulus-specific interference from weaker links at the cost of interference by task-related information due to automatic rule application (i.e. automatic use of the strong link between category and response). Such an account allows for an impact of the strength of activation of competing mappings. More precisely, the stronger competing associations are (e.g. strong residual activation of the competing mappings on a task switch, or strong effects such as in the Simon task) the more likely they are to interfere.

The idea that strong associations between stimulus categories and responses are the reason for shielding is related to findings from Metzker and Dreisbach (2009, 2011). The authors originally sought to investigate the shielding function in the Simon task, assuming that shielding might decrease or eliminate the Simon effect. Unexpectedly, Metzker and Dreisbach repeatedly found greater spatial compatibility effects in the TS group than in the SR group. Remember that shielding in the TS group had previously been found to prevent spatial interference by animal distracters (Dreisbach & Haider, 2009). Metzker and Dreisbach came up with an appealing explanation for their results. Usually, the Simon effect is explained by dual-route models. The identity of the target activates the correct response through the indirect route, whereas the irrelevant spatial location activates the corresponding spatial response via the direct route. If these two routes activate conflicting responses, reaction times are slowed. Adding to these two routes from stimulus features to response features, Metzker and Dreisbach proposed a third route that connects the spatial response code to the associated stimulus categories (see also Part I). This route allows the spatial location of the target to prime target identity if the location matches the target category. If, say, *moving objects* were associated with pressing the left key then presenting the target on the left hand side of the screen would not only activate the response *left* via the direct route, but also prime the category *moving objects.* In contrast, the identification of non-moving objects would profit from a target presented on the right. Metzker and Dreisbach proposed that the one-to-one mapping achieved by categorizing the targets allows for strong priming activation from the response code to the related category. On the other hand, with many-to-one mappings like in an SR condition, this priming effect suffers due to the fan effect (J. R. Anderson, 1974). The activation spreading from a spatial code to three associated targets (many-to-one, e.g. left →banana, left → lemon, left → pear) is reduced due to the fan effect and the priming ends up weaker than with only one associated target (one-to-one; e.g. left → *yellow fruit*).

The strong associations account is certainly well suited to explain why the (presumably rather weak) spatial information conveyed through the animals is shielded against, while other effects occur despite of shielding (e.g. the Simon effect, Metzker & Dreisbach, 2009; the SNARC effect, Wendt et al., 2013). If one were to assume that the latter are themselves served by strong (possibly natural) associations between a feature and a spatial response shielding might not be enough to overpower them as suggested. On another note, linking shielding to strong associations offers an explanation to results Dreisbach and Haider (2009) obtained in the SR group with extensive practice. If subjects practiced the separate mappings without the presence of distracters spatially oriented animals did not interfere later. Assuming that distracter-free practice led to a strengthening of the relevant associations, this might explain the lack of spatial congruency effects at a later point.

However, when it comes to the question of how shielding can prevent binding effects, the explanation is more difficult. First, based on the existent studies on shielding it cannot be decided whether a) binding simply does not occur, or whether b) binding and subsequent retrieval both occur but for some reason do not show in RTs. Consequently, how the shielding function works concerning binding effects depends on what assumptions are made about the occurrence of binding (yes or no) in the first place.

On the one hand, Dreisbach and Wenke (2011) interpreted their findings in terms of a lack of binding. The irrelevant feature (color/font) is *not bound* to the response. As a consequence, on task repetitions no interaction between feature and response is found. In this case, the fact that on task switches the interaction becomes significant is explained by assuming that a color switch (but not a color repetition) loosens the existing binding between the formerly relevant feature and the response (Spapé & Hommel, 2008). Therefore, on task switches the usual response repetition cost is found for color repetitions (because the response is still bound to the previously relevant category), but not for color switches (because the binding responsible for the effect is loosened by the color switch). Based on this explanation, the shielding mechanism should be able to prevent bindings between irrelevant features and responses. For this, associative strength between categories and responses does not seem sufficient. Rather, one would have to assume that an additional mechanism such as intentional weighting (Hommel, 2005, 2009; see also Dreisbach & Haider, 2008) prevents irrelevant features from being bound and that intentional weighting is more refined in subjects using task rules than in subjects using SR mappings. If this is true, shielding would consist of more than one underlying mechanism (unless one assumed that intentional weighting itself is served by strong associations). Shielding, the preferential treatment of task-related information, would be served by a) strong associations due to a biunique mapping and b) refined intentional weighting.

On the other hand, the results from Dreisbach and Wenke (2011) as well as previous results (Dreisbach & Haider, 2008) could alternatively be explained by assuming that the irrelevant feature is indeed bound to the response and retrieved later on, but does not lead to a strong enough trace to result in significant interference. That is, an event file is created that contains information concerning the task, the response, *and* features such as color or font. The subsequent presentation of the color then would lead to a retrieval of the corresponding response. However, in this case, the strong association between a category and a response is suited to explain why a comparably weak binding between color and response does not appear in RTs on task repetitions. At the same time, it explains why binding effects are found when shielding is relaxed on a task switch because now the retrieval of the response associated with the irrelevant feature competes with an association that is weaker than on task repetitions.

The proposal that shielding relies on the associative strength between categories and responses (due to the one-to-one mapping) has several implications. First, it is assumed that the locus of shielding is response selection (e.g. Glaser & Düngelhoff, 1984) rather than perceptual encoding[4] or response execution. The correct response is selected efficiently because the relevant association between target category and response is strong. Second, performance with a single SR mapping for each response should not differ from performance when a binary categorization rule is used. That is, rules are only useful if they reduce information (e.g. to one relevant feature or category). Likewise, using more than one category per response should weaken the shielding function.

IMPLICATIONS OF THE SHIELDING FUNCTION

The use of rules offers obvious advantages in real life. Information is reduced, important features are highlighted, and the possibility of generalization and transfer to novel situations or stimuli is offered. The present thesis showed that rule use offers another noteworthy advantage. By defining which features are relevant with regard to the response, the impact of distraction can be reduced. This finding – first and foremost – has implications for studies using rule-based instructions that base their interpretations on the existence or size of interference effects. The definition of a *task* is not straightforward and varies depending on the study (see Part I of the present thesis). However, as has been illustrated before and now again in this thesis, important aspects of performance, namely vulnerability to interference and stability of performance depend on how a task is represented. Although both SR mappings and categorization rules are sufficient for subjects to determine a correct response, these representations have different effects on cognitive control in the presence of distracting stimuli or features. Therefore, whenever the interpretation of an experiment is based on the absence, presence or magnitude of interference, a close look at how subject represent the task is necessary, especially when comparisons are made between groups. Depending on the distracter (irrelevant or related to the task), the representation of a task in terms of a categorization rule can reduce or enhance distractibility compared to SR representations. As a consequence, the quality of cognitive control in situations involving distraction depends on the type of task representation. This might affect measures such as the switch cost, binding effects, the Simon

[4] In line with this assumption, preliminary, unpublished results from recent experiments show that perceptual implicit memory for distracter stimuli does not differ in subjects using rules and subjects using SR mappings.

effect, the flanker effect, the SNARC effect, or the Stroop effect. Note that the representation of a task depends on more than mere instruction. Dreisbach and Haider (2009) showed that even with identical instructions the mode of introduction of targets led to the formation of categorization rules in some subjects but not in others. Specifically, when eight targets were introduced simultaneously instead of stepwise some subjects created their own rule for categorizing and showed the same pattern of results as subjects that were instructed to use a categorization rule (namely, no spatial congruency effects from animal distracters). Therefore, if different instructions are used or the instructions leave the possibility of interpretation concerning task representation, post-experimental interviews assessing subjects' strategy would be advised.

Moving away from cognitive control and task switching, the functionality of rule-based processing is also connected to other fields of psychological research. A preference for categorization rather than an exemplar-based strategy is not only found in experiments on task switching or shielding. In memory research, for instance, the possibility to use semantically related rather than unrelated stimuli has been shown to benefit performance when it is offered during encoding, as well as during recall (Epstein, Johnson, & Phillips, 1975; Tulving & Pearlstone, 1966). Another useful dissociation between rule-based manipulations (TS) and idiosyncratic exceptions (SR) comes from the area of linguistic studies, more precisely the English past tense (e.g. Marslen-Wilson & Tyler, 1998). Regular past tense is formed by adding the suffix –d, -ed, or –t to the word stem (e.g. *succeed* → *succeeded*), whereas irregular verbs diverge from this rule (e.g. *go* → *went*). It has been found that aphasic patients suffering from agrammatic speech are selectively impaired with regard to either irregular, or regular past tense, while the respective other tense and semantic priming are not affected. This dissociation between rule-based and irregular past tense can be used to address questions regarding the nature of mental computations (rule-based vs. operating without syntax) and bears some resemblance to the functional dichotomy between the use of task sets and SR mappings.

In a vein more similar to the kind of rule use applied in this thesis, Dreisbach (2012) pointed out that in developmental psychology differences in performance on the ability to switch and rule-based tasks are found in children of varying ages (e.g. Kharitonova et al., 2009; see also Part I). These are attributed to differing representations caused by developmental changes within the PFC. Functional differences in PFC and other brain areas of course can also be observed in patients suffering from lesions or particular diseases. Children with autism spectrum disorder, for example, are impaired in the formation of conceptual connections and therefore necessarily in rule-learning (Jones, Webb, Estes, & Dawson, 2013). This might be due to an atypical development of the PFC in such patients.

The implication of the effects of shielding on everyday life situations amounts to a simple and comprehensible advice: shop for *cocktail ingredients*, not limes, mint, and soda. You might end up buying rum, but it is still the better strategy. Phrased in more general terms, whenever you do not want to be distracted, use rules. Reduce information by categorizing your relevant targets, items, or bits of knowledge and thus shield yourself from irrelevant input. Of course, as was shown in Part I, rules can also enhance distractibility when the distraction is task-related. However, in real life it is safe to assume that task-related information is in fact relevant and is therefore most welcome to affect performance. On a more general level, social interactions can be affected by rule use. For instance, stereotyping might be considered an example of a task rule. People often stereotype to simplify or justify their opinions and behavior. They attribute traits considered typical for a certain group to a member of said group (TS) before finding out about individual habits and characteristics (SR). Telling you that I am German might prompt you to assume that I am punctual, like all sorts of sausages, and have no sense of humor. Only if you got to know me and looked beyond the category *German* you might find out that I like laughing, dislike some types of sausage, and that I am indeed punctual. Many factors, including motivational and emotional states have been shown to influence stereotyping (for a review see Hilton & von Hippel, 1996). But if stereotyping is viewed as a type of categorization rule, it might also offer a shielding function that contributes to its persistence. Based on the premise that shielding leads to preferential processing of related information, one might easily conclude that such a process contributes to the stability of stereotyping. Watching me arrive on time might make you strengthen your stereotype because you expected it. On the other hand, my pronounced gesticulation might go unnoticed seeing as it is not seen as typically German. Of course, this example is taking matters further than current results allow. Further research is necessary to allow for such transfer.

FUTURE DIRECTIONS

The present thesis addressed questions regarding the scope and mechanism of the shielding function of task sets. I could show that shielding is most probably a preference for task-related information and critically depends on task activation. An implication of the interpretation of shielding in terms of strong associations between target categories and responses is that perceptual and conceptual processing of distracter stimuli should not be affected. Even if subjects use rules and are therefore immune to interference by unrelated distracters, these should still be processed to the same degree as in subjects using SR mappings. Originally, Dreisbach and Haider (2009) had proposed "a global shielding mechanism that prevents the occurrence of response conflicts because the presumably interfering information is not being processed in the first place" (Dreisbach & Haider, 2009, p. 477). However, later research suggested “that the shielding function of task sets prevents irrelevant information from entering the response system” (Dreisbach & Wenke, 2011, p. 154). This latter account fits better with the favored explanation in this thesis. If shielding is indeed located at the stage of response selection, identification of distracter stimuli should not suffer. Goschke (2000) proposed that in order to enable flexible behavior, information currently considered distracting should still be processed to a level that allows identification. Otherwise, higher-level goals such as simple survival might be missed. The fact that task-related (noun-related) and target-related (noun) distracters always interfered in the current thesis already suggests that distracting information is not ignored when it comes to processing. However, proof is missing concerning unrelated distracters. Whether or not such distracter stimuli are processed to a perceptual and even a conceptual level might be investigated with the help of implicit memory tests. For instance, subjects could be asked to complete fragments of pictures previously presented as distracters (perceptual implicit memory; e.g. Ballesteros, Reales, García, & Carrasco, 2006). Conceptual implicit memory tests such as category exemplar generation (e.g. Bruss & Mitchell, 2009) might be used to assess whether the distracters were processed to a semantic level: if subjects name category exemplars that were earlier presented as distracters more often than comparable exemplars, previous conceptual processing of said distracters is likely. And in fact, concerning perceptual priming, preliminary data from unpublished studies support this assumption, whereas data on conceptual priming are still somewhat mixed. Further research is necessary to determine to what level distracters are processed.

The limitations of the procedures used so far are also a starting point for future research. Shielding has been investigated with word targets and distracting pictures or feature changes. Therefore, the procedure offers the possibility for expansion to enable more general conclusions. For instance, the temporal (speed of processing as well as time point of introduction) and spatial relationship between targets and distracters could be looked into. Recently, efforts have been made to broaden the scope of application of the shielding function. Studies using spoken words as targets and gender (word spoken by a man or a woman) or emotional state (e.g. word spoken by an angry or a happy voice) as an irrelevant feature found the very same binding effects between voice and response that Dreisbach and Haider (2008) had reported for written words and colors (Bogon, Eisenbarth, Landgraf, & Dreisbach, in preparation). Importantly, as before, these binding effects were only found in the SR group, not the TS group. This research opens up the possibility of transferring findings on the shielding function to social interaction. Interestingly, some results indicate that there might be a gender-specific component to shielding. However, direct investigation of this effect has not yet been attempted.

In sum, the shielding function of task sets as a means of promoting cognitive stability is simple, yet effective: Rules reduce information and thereby help with the execution of a task by allowing enhanced processing of what is relevant. However, when task activation is attenuated this advantage is temporarily reduced. The simplicity of this mechanism is appealing and holds the promise that future research will be rewarding. The extension of the paradigm and its applications will certainly yield interesting results. Alas, these are for others to unveil.

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