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ORIGINAL ARTICLE

That's what task sets are for: shielding against irrelevant information

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Abstract Goal-directed behavior requires the cognitive system to distinguish between relevant and irrelevant information. The authors show that *task sets* help to shield the system from irrelevant information. Participants had to respond to eight different colored word stimuli under different instruction conditions. They either had to learn the stimulus–response mappings (SR condition), to use one task set (1 TS condition) or to use two different task sets (2 TS condition). In the 2 TS and the SR conditions, participants showed response repetition effects (interaction of color repetition × response repetition), indicating that participants processed the color of the words. Importantly, the 1 TS condition did not show such an interaction. Overall, the results provide evidence for the shielding function of task sets. This benefit turns into costs in classical task switching paradigms. From this perspective, switch costs can be interpreted as the consequence of successful shielding on the previous task.

Introduction

One of the hallmarks of human cognition is the ability to pursue goal directed behavior in the face of distracting information. To this end, the cognitive system must be able to distinguish between relevant and irrelevant information with respect to a current goal. In this paper, we argue that task sets, that is, cognitively represented rules that define relevant stimulus and response features for a given task, shield attention from distraction from features that are not part of the specified task set. In other words, we assume that the function of task sets is to guide attention towards relevant information and to shield attention from irrelevant information.

The term task set is closely tied to the task switching paradigm, where task sets typically consist of simple two-choice categorization rules: for example, deciding whether or not a given word represents an animal, or deciding whether a word starts with a consonant or a vowel (Dreisbach, Haider, & Goschke, 2006; Dreisbach, Haider, & Goschke, 2007). A common and very robust finding when switching between tasks is that performance on task repetitions is faster and more accurate than performance on task switches (Allport, Styles, & Hsieh, 1994; Dreisbach, Haider, & Kluwe, 2002; Dreisbach & Haider, 2006; Rogers & Monsell, 1995; Meiran, Chorev, & Sapir, 2000; for a review see Monsell, 2003). Within the task switching literature, these findings are typically interpreted as switch costs. In the case of a task switch, the previously relevant stimulus and response features now have to be ignored whereas the previously ignored features now have to be processed (Allport & Wylie, 2000; Wylie & Allport, 2000). In this paradigm, however, any advantage of task sets for the cognitive system can only indirectly be inferred from the costs that occur as soon as the task set changes. After nearly 15 years of extensive research on task switching, it therefore seems timely to show that task sets do not always produce costs and interfere with each other, but rather to show directly that task sets help the cognitive system to shield

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against task irrelevant distractions. Our goal therefore is to provide straight evidence for the beneficial effects of the shielding function of task sets.

Of course, there might be other advantages of task sets aside from the assumed shielding function. One obvious benefit of task sets is that it allows for an information reduction and thereby reduces working memory load. However, these beneficial effects are not easy to detect: In recent research from our labs, we compared task performance between conditions where participants either had to switch between two simple cognitive tasks (2 TS condition hereafter) or had to learn eight different stimulus response mappings directly (the very same stimulus set) without any knowledge about the underlying task sets (SR condition, hereafter; see Dreisbach et al., 2006, 2007). Surprisingly, it turned out that performance of the SR condition was always superior to the performance of the 2 TS condition: Participants were significantly faster in the SR condition than participants in the 2 TS condition and, of course, did not produce any switch costs (Dreisbach et al., 2006). We then reasoned that the advantage of task sets might become evident as soon as new stimuli are introduced: Whereas participants would have to learn the new stimulus set from scratch in the SR condition, participants should be able to apply the already learned and trained task sets to the new stimuli without any transfer cost in the 2 TS condition. However, when we introduced eight new stimuli in a transfer block at the end of the experiment, the SR group again outrivaled the 2 TS group: they were still faster and did not show any transfer costs.[1] In a further experiment, we found out that in the SR condition, participants actually adopted implicit knowledge about the underlying task sets: When confronted with SR mappings in the transfer condition that did not match with the underlying task sets, participants produced transfer costs (Dreisbach et al., 2006).

In sum, these recent studies did not provide any evidence for the beneficial effects of (at least explicitly instructed) task sets; in contrast, performance of the SR condition was always superior to the 2 TS condition. Thus, it seems that our former experiments failed to show any beneficial effect of (explicitly instructed) task sets (in our defense, this was not the actual goal of our former research). As stated above, the task switching experiments provide at least indirect evidence for a shielding function of task sets by showing, for example, that information irrelevant for the actual task is inhibited (e.g., Mayr & Keele, 2000). However, direct evidence is missing that task sets help the system to shield against irrelevant information. One reason might be that this shielding function of task sets turn into costs as soon as the task set changes, because in this case, the formerly irrelevant and ignored information now has to be processed. That is, the shielding function of task sets might not be detectable in common task switching settings but only in a task repetition setting. The idea of the current experiment was to introduce a new task set condition in which participants base their task processing on just one task set, and to compare performance between this newly introduced one-TS condition (1 TS) and the former SR and 2 TS conditions. More precisely, all participants will work through the same set of stimuli while they will be instructed either to use direct SR-mappings, one task set, or two task sets. Thus, participants in the three different instruction conditions will carry out exactly the same actions on exactly the same stimuli. The only difference between conditions will be the implementation of different task representations to accomplish the task. All participants will receive a set of eight different words that will be unequivocally mapped to two responses. Four words will be written in red, four words will be written in green. Two words of each color will be mapped to one response, such that the color will not correlate with a specific response (see Table 1). Participants either learn the single stimulus–response-mappings by heart (SR condition), or they use one task set (does the word represent a moving object or not, 1 TS condition), or they switch between two task sets according to the color of the word (green: word represents an animal or not, red: word starts with a consonant or a vowel; 2 TS condition). Note that the color is only task relevant in the 2 TS condition, but completely irrelevant in the SR and 1 TS conditions. This procedure allows investigating directly, whether a task set actually helps to shield attention against task set irrelevant information (here, the color of the words). From

Table 1 Stimuli and corresponding responses

Two task sets (2 TS)	One task set (1 TS)	
	Moving	Non moving
	Left response key	Right response key
Stimulus-color: green		
Animal	Laus (2), Iltis (4) (bug, polecat)	
No animal		Sofa (1), Ulm (3) (sofa, Ulm)
Stimulus-color: red		
Consonant	Bein (1), Pendel (3) (leg, pendular)	
Vowel		Anker (2), Eis (4) (anchor, ice)

Note, that the mappings of the colored words to the left and right response keys were exactly the same irrespectively of the given task instruction (SR, 1 TS, or 2 TS). Numbers in parentheses indicate the block in which the stimuli were introduced

[1] Of course, if we had introduced, say, a set of 50 new stimuli at once, we probably would have found better performance in the 2 TS condition as compared to the SR condition.

previous research we know that even though participants in the SR condition do not produce any color switch costs (slower response times when the stimulus color switches as compared to stimulus color repetitions), the irrelevant color feature still interacted with the response: color repetitions were faster along with response repetitions as compared to response switches, however, color switches were faster along with response switches as compared to response repetitions (Dreisbach et al., 2006). These response repetition effects, thus, clearly show that the irrelevant color feature was also processed in the SR condition (see also Campbell & Proctor, 1993; Notebaert & Soetens, 2003; Pashler & Baylis, 1991; Soetens, 1998). Now, if our assumption proves right, and task sets help to guide attention towards relevant information and to shield from irrelevant information, this color by response interaction should not occur in the 1 TS condition because in this condition, the one task set directs attention towards the semantic content of the words and shields against irrelevant information (here: stimulus color). In the 2 TS condition (the second control condition aside from the SR condition), color is a task inherent stimulus feature and, thus, task relevant. We therefore expect classical (color) switch costs as the two task sets require participants to switch between different tasks (see also Dreisbach et al., 2006, 2007). The shielding function of task sets in this 2 TS condition then can only indirectly be inferred, if we assume that switch costs result from the successful shielding from irrelevant information in the previous trial. Therefore, we also expect a response by color interaction in this latter condition. Such response repetition effects have first been described by Rogers and Monsell (1996) and have repeatedly been observed within the task-switching paradigm since (Hübner & Druey, 2006, 2007; Kleinsorge, 1999; Kleinsorge & Heuer, 1999; Mayr & Kliegl, 2003; Meiran, 2000a, b; Schuch & Koch, 2004; for interpretations of this effect see General discussion).

In sum, we expect color by response interactions in the SR and 2 TS conditions but not in the 1 TS condition where the one task set helps to shield the cognitive system against the irrelevant color feature of the stimuli. Furthermore, we expect to replicate previous findings, namely a main effect of color switch in the 2 TS condition.

Method

Participants

Seventy-five students (mean age = 22.65, SD = 2.9, range 18–29, 44 female) of the Dresden University of Technology participated for partial course credit or a small financial reward (2€). 25 participants were assigned to each of the three experimental conditions.

Stimuli and procedure

Four German words written in red (Bein, Pendel, Anker, Eis [leg, pendulum, anchor, ice]) and four German words written in green (Laus, Iltis, Sofa, Ulm [bug, polecat, sofa, Ulm]) served as stimuli. Response keys were the two outermost keys on the left and right side of the bottom of a computer keyboard. Two words of each color were assigned to the left key (Bein, Pendel, Laus, Iltis); the remaining words were assigned to the right key. The stimuli were introduced in steps of two words per block in order to reduce working memory load especially in the SR condition, and to minimize the chance that participants in the SR condition might guess the underlying task sets when confronted with the complete stimulus set at once (in a post-experimental interview nobody guessed the underlying task rules). From previous experiments with a comparable paradigm we know that this procedure does not alter task-switching performance in the 2 TS condition (see Dreisbach et al., 2006, 2007). In the first block, only two different words were presented, and then stimulus set size increased by two with every block, such that, in Blocks 4, 5 and 6, all 8 words appeared. Each word was presented ten times per block, resulting in a block length of 20 trials for the first block, 40 trials in the second block, 60 trials in the third block and 80 trials in all remaining blocks. Blocks 2–4 additionally started with six practice trials featuring only the new stimuli, but were discarded from the analysis. Target stimuli were randomly presented. Stimulus repetitions were allowed but were excluded from further analyses.

Any given trial started with a fixation cross of 400 ms duration followed by a blank screen of 400 ms. Then, the target word appeared and remained on the screen until a response was given. After an intertrial interval (ITI) of another 400 ms, the next trial started. When participants responded erroneously, they received feedback and ITI was extended to 2,000 ms.

Before each block, participants were informed about the two new SR mappings. After Block 4, they received a scheme that listed all eight SR mappings and were told that no more words would appear. This procedure was identical in all conditions, but the task instruction differed. In the SR condition, participants were informed at the beginning that we were interested in how easily they assigned words to specific responses. In the 1 TS and 2 TS condition, participants were told at the beginning of the experiment that we were interested in how easily they assigned words to specific categories. Participants in the 1 TS condition were instructed to press a left key whenever the word presented a moving object and to press a right key whenever the word did not present a moving object. Participants in the 2 TS condition were instructed that whenever a red word appeared, they would have to decide whether the word started with a consonant (left key) or a vowel (right key). Whenever a green word appeared, they had to decide whether the word represented an animal (left key) or not (right key). In the 1 TS and 2 TS conditions these decision rules were mentioned at the beginning and only were repeated after Block 4, followed by the scheme that listed all eight words together with the tasks, and the response keys.

Design

A 2 (color: switch vs. repetition) × 2 (response: switch vs. repetition) × 6 (Block) × 3 (instruction condition: SR, 1 TS, 2 TS) mixed factors design was applied. Note that the color switch in the 2 TS condition represents a task switch and the color repetition correspondingly a task repetition. Instruction condition was manipulated between participants; all other factors were manipulated within.

Results

Incorrect responses and those following an error were excluded from the analysis. All stimulus repetitions were also excluded. Furthermore, we will only report the results for Blocks 4–6 where all eight stimuli had already been introduced.[2] To control for RT outliers we computed individual median RTs per factor cell. We will first report Mean RTs (i.e., means of the individual medians) and errors of color shifts and repetition per block and instruction condition. Second, we report the results for the response repetition effects. In all analyses reported here, the adopted significance level was $\alpha = 0.05$. For significant effects, individual p values are not reported.

Overall analyses

RT data

Figure 1 depicts mean RTs as a function of color repetition, block and instruction condition. A 3 (instruction condition) × 2 (color) × 3 (block) mixed factors ANOVA with repeated measures on the last two factors yielded significant main effects of Block, $F(2,144) = 32.72$, MSE = 4336.10, $\eta^2 = 0.31$, and color, $F(1,72) = 5.68$, MSE = 2650.28, $\eta^2 = 0.07$, whereas the main effect Instruction did not prove reliable ($F = 1.3$, $p = 0.28$). Furthermore, the interactions Instruction by block and instruction by color proved reliable, $F(4,144) = 2.95$, MSE = 4336.10, $\eta^2 = 0.07$ and $F(2,72) = 3.60$, MSE = 2650.28, $\eta^2 = 0.09$, respectively. No other effect was significant (both $F < 1.8$, $p > .14$). The color by instruction interaction is due to the fact that color shifts in the 2 TS condition are significantly slower than color repetitions, that is, switch costs were significant in this condition, $F(1,72) = 12.56$; MSE = 2650.28, $\eta^2 = 0.21$, but were not in the SR, or in the 1 TS conditions (both $F < 1$, both $p > 0.5$).

Error rates

Error data are also presented in Fig. 1. A 3 (instruction condition) × 2 (color) × 3 (block) mixed factors ANOVA with repeated measures on the last two factors yielded a main effect for Block, $F(2,144) = 5.22$, MSE = 58.06, $\eta^2 = 0.07$, and color, $F(1,72) = 5.08$, MSE = 17.82, $\eta^2 = 0.07$, the main effect Instruction condition and all interactions were not significant (all $F < 2.2$, all $p > 0.1$).

Response repetition effects, RT data

In order to get more reliable data for the response repetition factor, we collapsed the data over blocks 4–6 (where all eight stimuli had been introduced).[3] Figure 2 depicts mean RTs as a function of instruction condition, color, and response. As can be seen on first glance, a color by response interaction is present in the SR and 2 TS conditions, but is absent in the 1 TS condition. A 3 (instruction) × 2 (color) × 2 (task) mixed factors ANOVA with repeated measures on the last two factors reveals a significant main effect of color, $F(1,72) = 5.8$, MSE = 2056.51, $\eta^2 = 0.07$, indicating that, overall, color shifts were answered significantly slower than color repetitions (593 vs. 506 ms). More importantly, there were significant interactions instruction by color, $F(2,72) = 5.80$, MSE = 2056.5, $\eta^2 = 0.10$, and color by response, $F(1,72) = 26.60$, MSE = 686.7, $\eta^2 = 0.27$, which were substantiated by a triple interaction instruction × color × response, $F(2,72) = 6.65$, MSE = 686.74, $\eta^2 = 0.16$.[4]) No further effect was reliable (all $F < 1.0$, all $p > 0.3$). The triple interaction supports the above mentioned impression that the response × color interaction was significant in the SR and 2 TS conditions, $F(1,72) = 13.88$, MSE = 686.7, $\eta^2 = 0.33$, and $F(1,72) = 26.02$, MSE = 686.7, $\eta^2 = 0.42$, respectively, whereas it was completely absent in the 1 TS condition, $F < 1$, $p > 0.9$.

[2] An additional analysis including the first three blocks did not provide any further information but can be reported on request.

[3] We also ran an additional analysis including block as separate factor. Aside from a main effect block and a significant interaction block × instruction, no further higher order interaction including block and instruction proved reliable.

[4] In order to rule out that this triple interaction color × instruction × response is solely due to the color × response interaction in the 2 TS condition, we ran the same analysis without this 2 TS condition. The triple interaction, however, remained highly significant, $F(1,48) = 8.58$; $p < 0.01$.

Fig. 1 (*Color*) shift costs in Blocks 4–6: mean RTs (ms) and error rates (%) are shown as a function of color type, and block in the three instruction conditions. *Error bars* represent 95% within-participant confidence intervals based on the corresponding color repetition vs. color shift comparison (Loftus & Masson, 1994)

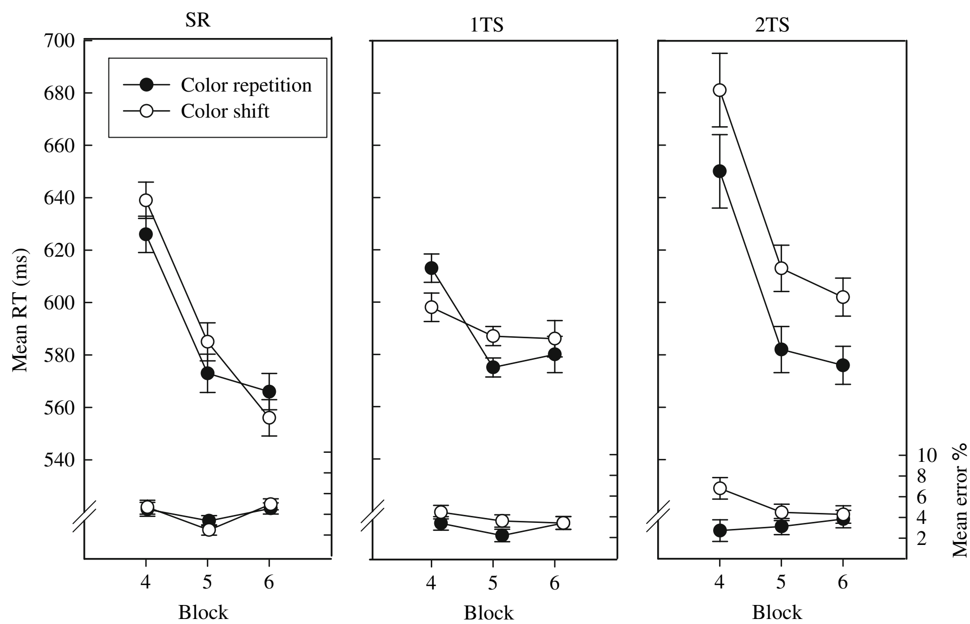
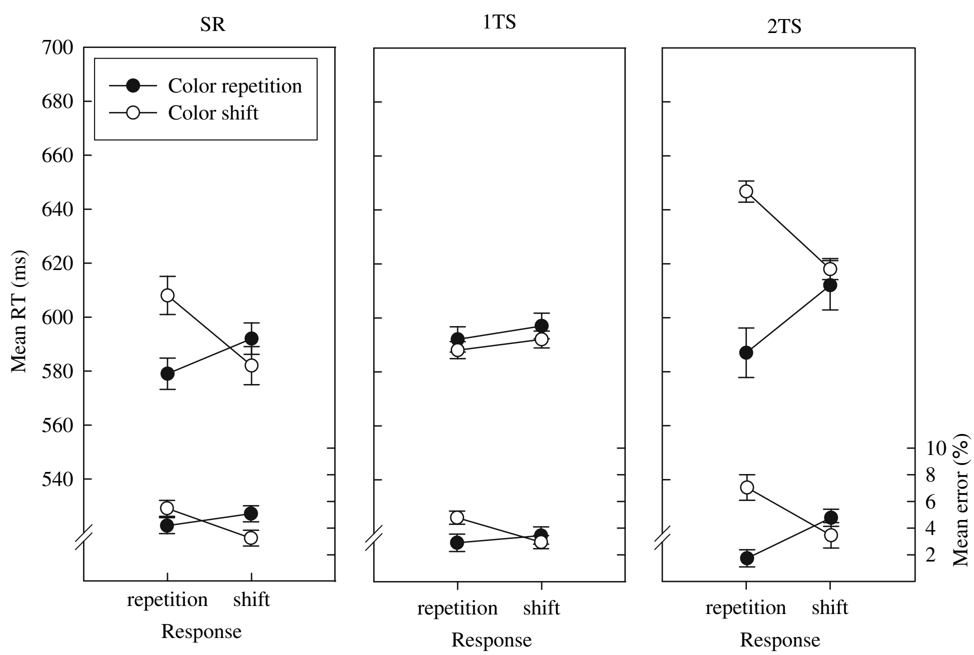


Fig. 2 Response repetition effects collapsed over block 4–6: mean RTs (ms) and error rates (%) are shown as a function of color type, and response type in the three instruction conditions. *Error bars* represent 95% within-participant confidence intervals based on the corresponding response repetition vs. response shift comparison (Loftus & Masson, 1994)



Response repetition effects, error rates

Error data are presented in Fig. 2. A 3 (instruction) × 2 (color) × 2 (response) mixed factors ANOVA yielded a significant main effect of color, $F(1,72) = 4.31$, $MSE = 11.38$, $\eta^2 = 0.07$, indicating that color switches were slightly more error prone than color repetitions (3.7 vs. 4.5%). This time, only the interaction color × response proved reliable, $F(1,72) = 26.39$, $MSE = 11.5$, $\eta^2 = 0.27$, whereas instruction × color as well as the triple interaction instruction × color × response were only marginally significant, $F(1,72) = 2.84$, $MSE = 11.3$, $p = 0.06$, $\eta^2 = 0.07$, and $F(1,72) = 2.76$, $MSE = 11.5$, $p = .06$, $\eta^2 = 0.07$. Further analysis showed that the color × response interactions were again highly significant in the SR and 2 TS conditions (both $p < 0.001$), this interaction failed to reach level of significance in the 1 TS condition ($p = 0.08$).

Discussion

The above-presented results support our assumption of the shielding function of task sets: The color feature interacted with response type in the 2 TS and SR conditions, but it did not in the 1 TS condition. This second order interaction was clearly found in the RT data and less unequivocally in the error data. Even though the overall interaction Instruction by color by response just failed significance in the error data, the color by response interaction was significant only in the SR and 2 TS conditions, but was again not significant in the 1 TS condition. Thus, we cannot definitely rule out that the color feature influenced task performance in the 1 TS condition (see also Kleinsorge, 1999; Notebaert & Soetens, 2003), but the effect is clearly attenuated.

Taken together, the presented data provide general support of our idea that one function of task sets is to shield attention from distracting information. Participants in the 1 TS condition were not influenced by the irrelevant color feature, whereas participants in the SR condition obviously were. The 2 TS condition shows that the advantage of this shielding function turns into costs when switching between tasks. In the case of a switch, participants have to attend to those stimulus features they had successfully ignored in the previous trial. However, the assumed shielding function of task sets in the 2 TS condition can only indirectly be inferred by the observed switch costs and the response repetition effects. By contrast, the null effect in the 1 TS condition represents the first direct evidence for the widely accepted view that switch costs can in part be attributed to the shielding function of task sets.

Alternatively, the pattern of results might also be due to differential working memory (WM) demands in the SR and 1 TS condition (i.e., higher WM load in the SR-condition). In the field of visual selective attention, DeFockert, Rees, Frith, and Lavie (2001) brought up evidence that the interference by irrelevant stimulus features increases with increasing WM load. Taken this into account, one might argue that it is this reduced WM load in the 1 TS condition that modulated the response repetition effects. As already stated in the "Introduction", we agree that task sets help to reduce WM load. So far however, we cannot decide whether the improved shielding in the TS condition results from or causes the reduced WM load.

On a more general level, the results presented here, by and large, fit with the alternative response repetition accounts discussed in the task switching literature: According to Hübner and Druey (2006), these accounts can be divided into five not mutually exclusive interpretations: (1) A learning mechanism that binds the stimulus category with the response such that a category switch that affords the same response, requires this response to be unbound from the previous category (e.g. Meiran, 2000a, b). (2) A binding mechanism in which, as soon as a task is carried out, stimulus and response features are bound into one episode which has to be overcome as soon as the task changes (Hommel, 1998; Hommel, Müsseler, Aschersleben, & Prinz, 2001). (3) According to Schuch and Koch (2004), the response that is carried out receives a certain meaning, which leads to confusion in the case of a task switch, because the same response now has a different meaning. And finally (4), Hübner and Druey themselves propose a response suppression mechanism that prevents the erroneous re-execution of the same response: In the case of a task repetition, this suppression is outweighed by the advantage of carrying out the same task whereas it results in costs if a switch is required.

Both, the learning mechanism where a certain stimulus category gets bound to the response which has to be overcome in case of a task switch (Meiran, 2000a, b), as well as the switch of response meaning that causes irritation (Schuch & Koch, 2004), suit our results: In the 1 TS condition, a color switch does not necessarily go along with a category switch or a switch of response meaning. And consequently, the color switch does not interact with the response. In the SR condition, in contrast, one might say that any stimulus switch goes along with a category switch and a response-meaning switch (because no supervisory categories are involved). Consequently, color switch interacts with the response.

Explaining our data with episodic feature binding, however, is a little bit more complicated. Remember that according to the binding hypothesis, stimulus and response features are bound together as soon as a task is carried out. This binding then has to be overcome when the same stimulus attributes appear, but a different response is required. This could easily explain the response repetition effects in the SR and 2 TS condition. However, such binding effect did not occur in the 1 TS condition. Presumably, the instructions led to an "intentional weighting" (e.g. Hommel et al., 2001, Wenke & Frensch, 2005) of those stimulus features that are mentally represented as task relevant: In the 1 TS condition, semantic stimulus features, but not color, is interpreted as task relevant; in the 2 TS condition, the color along with semantic and syntactic stimulus features is interpreted as task relevant; and finally, due to no specific instruction in the SR conditions, any stimulus feature (also the color feature) might be taken as task relevant.[5] Consequently, the color feature would attract less attention in the 1 TS condition, but not in the other conditions. According to this "intentional weighting" hypothesis, the binding of stimulus and response features would represent an automatic consequence of having (intentionally) directed attention towards the respective stimulus features which, however, got interrupted by a task that requires to switch attention to other than the actually attended stimulus features (see also, Ansorge & Neumann, 2005).

Our data are also in line with the response suppression account as proposed by Hübner and Druey (2007, 2006). According to this assumption, any response is suppressed after its execution in order to prevent the system from its erroneous re-execution. This mechanism can explain the

[5] Alternatively, the binding of color and response in the SR condition might have occurred by default, that is, automatically and not due to the assumed task relevance of the color.

response repetition effects of the SR and 2 TS condition, as well as the absence of the response effect in the 1 TS condition because here, the disadvantage of the response suppression is outweighed by the repetition of the category. And finally, our data also fit with the assumption proposed by Kleinsorge and Heuer (Kleinsorge, 1999; Kleinsorge & Heuer, 1999) that any change of a task feature that is part of the task representation will lead to response repetition costs, if we assume that the color feature was part of the representation in the SR and 2 TS condition, but that it was not in the 1 TS condition.

In sum, our assumption of a shielding function of task sets does not rule out the alternative explanations of response repetition effects discussed in the literature. However, our account seems more suitable to explain response repetition effects in both, task switching and simple RT tasks. And on a more general level, the results presented in this study also might help to better understand the occurrence of switch costs and the functional value of task sets. After nearly 15 years of extensive research on task switching (since Allport et al's. rediscovery of the paradigm in 1994), this is the first time that the beneficial effects of task sets have been shown directly. We provided evidence that task sets do not always produce costs and interfere with each other, but that task sets might rather help the cognitive system to shield from task irrelevant distraction.

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