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ORIGINAL ARTICLE

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The role of task rules and stimulus–response mappings in the task switching paradigm

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Abstract Switch costs occur whenever participants are asked to switch between two or more task sets. In a typical task switching experiment, participants have to switch between two task sets composed of up to four different stimuli per task set. These 2 (task sets) × 4 (stimuli) contain only 8 different stimulus–response (S–R) mappings, and the question is why participants base their task performance on task sets instead of S–R mappings. The current experiments compared task performance based on task rules with performance based on single stimulus–response mappings. Participants were led to learn eight different S–R mappings with or without foreknowledge about two underlying task sets. Without task set information no difference between shifts and repetitions occurred, whereas introducing task sets at the beginning led to significant switch costs. Most importantly, introducing task sets in the middle of the experiment also resulted in significant switch costs. Furthermore, introducing task rules at the beginning of the experiment lead to slower RTs when simple stimuli (Experiment 1) had to be processed. This detrimental effect disappeared with more complex stimuli (Experiment 2). Results will be discussed with respect to cognitive control.

Introduction

One of the hallmarks of intelligent organisms is their ability to flexibly switch between different goals and actions. Whenever an action has to be interrupted in favor of carrying out another action, it is assumed that executive control comes into play. Imagine for example sitting in your office writing a paper. While you are writing you get an alert signaling an incoming e-mail. You could either stop writing and answer the e-mail or you could continue your work and postpone your answer for an indefinite time. If you go for the former, this switching of actions will typically be accompanied by additional costs, the so-called switch costs. In order to investigate the processes underlying the switching of cognitive task sets, cognitive psychologists established the task switching paradigm (Jersild, 1927; Sepctor & Biedermann, 1975; Allport, Styles & Hsieh, 1994). In a typical switching paradigm, participants are informed at the beginning of the experiment about the occurrence of two or more categorization tasks (e.g., deciding whether a letter is a consonant or a vowel and deciding whether a digit is odd or even). Basically, results of such experimental setups show that participants need more time to conduct task switches (the category to be processed differs from that processed in the preceding trial) than task repetitions (the category does not change between trials). Several authors assume that these switch costs reflect the time the cognitive systems needs to reconfigure itself to the changed task demands, thereby reflecting an active process of goal shifting (Goschke, 2000; Logan & Gordon, 2001; Meiran, 1996; Monsell, Yeung & Azuma, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer & Evans, 2001). However, and alternatively, one might as well argue that switch costs reflect the fact that task repetitions are answered faster and more accurately due to a carryover effect, namely the persisting activation of the recent execution of the same task, such that the term repetition benefit would more appropriately describe the phenomenon (Allport & Wylie, 2000, Altmann, 2004a, 2004b; Dreisbach, Haider & Kluwe, 2002; Dreisbach & Haider, 2005; Koch, 2001, 2003; Logan & Bundesen, 2003; Ruthruff, Remington & Johnston, 2001; Sohn & Anderson, 2001; Sohn & Carlson, 2000; Wylie & Allport, 2000). It is important to note that this

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latter view does by no means deny the involvement of cognitive control processes in the task switching paradigm per se. Rather, it assumes that both, task switches *and* task repetitions, underlie processes of cognitive control and thus switch costs do not reflect an appropriate measure of cognitive control processes (see also Gilbert & Shallice, 2002).

But whatever position might turn out to be right, the fact that switching between simple cognitive tasks is accompanied by a cost at all is by itself worth further inspection! Remember that in a lot of task switching experiments, participants have to switch between just two task sets that contain a maximum of up to four stimuli (e.g., Meiran, 1996, 2000; Goschke, 2000); that is, these experiments actually contain only eight different S–R mappings or sometimes even less. So, a much more efficient strategy would be if participants based their task performance on direct stimulus–response rules (S–R mappings or a compound stimulus strategy if participants have to use cues in order to process the entire task; Logan & Bundesen, 2003) instead of task rules. Note that we do not deny the relevance and utility of rule-based processing in general. Task rules are useful and often necessary to reduce complexity. However, in simple task switching experiments with a circumscribed number of S–R mappings and long periods of practice, this rule-based processing does not seem to be the most efficient strategy to us.

However, results of task switching experiments suggest that participants do not learn to apply direct S–R mappings, or, at least, we do not know whether or not they base their performance on S–R mappings even when task processing allows for relying on only the S–R mappings (for an exception see, e.g., Mayr & Bryck, 2005). Take the following example: the digits 2, 3, 7, 8 written in red or green serve as stimuli. Participants either have to judge whether a green digit is odd or even or whether a red digit is smaller or bigger than 5. In such an experimental setup one would typically find switch costs: whenever a participant switches from one task to another, responses are slower than when the task is repeated. However, participants could also base their performance on direct S–R mappings which would render the application of the task rules unnecessary. In the given example, participants could thus learn to map the green digits 2 and 8 and the red digits 2 and 3 to the left response key and the remaining stimuli to the right response key. In this case, we would expect to find no switch costs, as task switching is not necessary. Thus, even though it seems that a direct S–R mapping strategy is a much more efficient strategy, the task switching literature suggests that participants do not adopt (or at least do not completely adopt; Arrington & Logan, 2004) this strategy. The occurrence of switch costs is probably one of the most robust findings in the cognitive literature. Furthermore, switch costs do not disappear even after long periods of practice and even with completely disambiguated stimuli (Dreisbach et al., 2002, Experiment 3), suggesting that participants are not able to disengage from using task rules once they are established. So, why is it that participants never use direct S–R mappings albeit it seems to be the more efficient strategy? One obvious and very straightforward explanation could be that the number of S–R mappings simply exceeds working memory capacity (at least at the beginning of an experiment, right after the introduction of the stimuli), such that the task rules are necessary in order to fulfill the task requirements. This is probably true for some experiments using more than four stimuli per task (or more than two tasks) but, as already mentioned above, a lot of task switching experiments use only a small number of stimuli that does not exceed working memory capacity. A second possible reason (which is not mutually exclusive with the first) is that task instructions at the beginning of a task switching experiment establish a mental task representation that cannot be overcome once it has been established (Mayr & Bryck, 2005). In the experiments presented here, we will focus on this explanation which is in accordance with the so-called episodic retrieval account (e.g. Allport & Wylie, 2000; Hommel, Pösse & Waszak, 2000; Waszak, Hommel & Allport, 2003). This account assumes that the first application of a task rule to a specific stimulus is memorized in episodic memory and will automatically be retrieved whenever the stimulus occurs again (see, e.g., Mayr & Kliegl, 2000, 2003).

The goal of the current experiments therefore was to directly investigate the role of task sets and single S–R mappings in the task switching paradigm. The basic assumption was that participants should produce switch costs when their task performance relies on task rules, whereas they should not when relying on S–R mappings (e.g., Arrington & Logan, 2004). More precisely, we examined two questions: (a) would participants use task rules even when the experimental setup suggests the use of direct S–R mappings and (b) would pure knowledge about the existence of task rules affect task performance even when the S–R mappings had already been learned and used?

For this purpose, all participants received a total of eight different stimuli successively: participants started with just two stimuli in the first block of practice. Then, the set size was increased by two in three consecutive blocks until a total of eight different S–R mappings had been reached. This pair-wise introduction of stimuli should ensure that participants could learn and use direct S–R mappings as a possible and efficient strategy. After having introduced all eight S–R mappings, all participants received two further blocks of practice.

In order to investigate the role of task rules, participants either were told about the task rules right at the beginning of the experiment (Early Information condition), after having introduced all eight S–R mappings (Late Information condition) or did not receive any information about the task rules (Uninformed condition). Thus, participants in all three conditions learned and practiced the same number of different S–R mappings, but differed in their knowledge about the underlying task rules.

This paradigm allows us to answer the following three questions concerning the role of task sets: Would participants in the Early Information condition still show switch costs even though the stepwise introduction of the task stimuli suggests the use of direct S–R mappings? Would participants in the Late and Uninformed conditions be able to learn and use the eight different S–R mappings successfully? And finally, would the introduction of task rules in the Late Information condition affect task performance even after S–R mappings had been practiced?

Experiment 1

Method

Participants

Sixty students (42 females, mean age 23.06, SD 3.00, range 17–32) from the Dresden University of Technology participated for a small financial reward (€ 2). Twenty participants were assigned to each of the three experimental conditions, respectively.

Stimuli and procedure

Four German words written in red [“Bett, Sieb, Arm and Eis” (bed, strainer, arm, ice)] and four words written in green [“Rabe, Igel, Haus and Uhr” (raven, hedgehog, house, clock)] served as task stimuli. Response keys were the two outermost keys on the left and right sides of the bottom of a computer keyboard. Two words of each color were assigned to the left key (bed, strainer, raven and hedgehog); the remaining words were assigned to the right key. Each 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. Feedback was only given for incorrect responses in which case the ITI was extended to 2,000 ms.

The experiment consisted of six blocks. In the first block only two different words were presented, and then stimulus size increased by two with every block, such that, in Blocks 4, 5 and 6, all target words appeared (see Table 1).

In a given block, each word appeared ten times, resulting in a block length of 20 (first block), 40 (second block), 60 (third block) and 80 (fourth, fifth, sixth). Target stimuli were presented at random. Stimulus repetitions were allowed but excluded from the analyses (11.4% in Blocks 2–6). Because of the increasing work load on WM, Blocks 3 and 4 started with six practice trials, only featuring the new additional two words which, however, were also excluded from the analysis. The number of task switches and task repetitions was counterbalanced across blocks. This procedure was identical in all conditions. The information was manipulated by the written instructions. The *Early Information* condition was informed at the *beginning* of the experiment that we were interested in how easily humans assign words to specific *categories*. Participants were informed 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). They were then told that the experiment started easily, with just two words but that it would get more and more difficult. The first two words were presented with the corresponding response keys and the first block started. Before every subsequent block, participants were informed which two further words would additionally appear in the next block. However, the decision rules were only repeated after Block 4 (together with a scheme that listed all eight words, together with the tasks and the response keys) when all eight S–R mappings had been introduced and never were participants explicitly asked to use this rule. After Block 4, participants learned that no further words would be introduced. In the *Late Information* condition, participants were told at the beginning of the session that we were interested in how easily humans assign words to specific *reactions* (instead of categories, see above). Thus, participants were simply informed about the specific stimulus–response mapping of each additional word-pair before each block. After Block 4, participants were asked what kind of memory strategy they had used to remember the words and responses (in both experiments no one guessed the actual task rules). After that, they were casually informed about the rules but not explicitly told to use them in the following blocks (“Maybe, you realized that there was a certain rule behind the assignment of words and response keys...” together with a scheme of all words, rules and response keys). They also knew that no new words would appear in Blocks 5 and 6. The *Uninformed* condition received the same instructions as the Late Information condition. However, after Block 4, they were simply told that no further words would be introduced and asked to work through another two blocks. This

Table 1 Order and number of words and corresponding response key per block in Experiment 1

Stimulus color and task	Response	Block 1	Block 2	Block 3	Blocks 4–6
Red Consonant–vowel	Left	Bett	Bett	Bett Sieb	Bett Sieb
	Right		Arm	Arm	Arm Eis
Green Animal–no animal	Left		Rabe	Rabe	Rabe Igel
	Right	Haus	Haus	Haus Uhr	Haus Uhr

group, hence, never was informed about the task rule. They were asked at the end of the experiment what kind of strategy they had used to remember the words (again, in both experiments no one guessed the actual task rules).

Design

A 3 (Information condition: early, late, no) × 6 (Block: first, second, third, fourth, fifth, sixth) × 2 (Task type: repetition, shift) repeated measures design was used. Information was manipulated between participants, Block and Task type were manipulated within participants.

Results and discussion

Incorrect responses and those following an error were excluded from the analysis. Furthermore, data from Block 1 were excluded from the analysis because with only two S–R mappings a task repetition is always a stimulus repetition. Furthermore, all stimulus repetitions were also excluded. For each participant, we then computed individual median reaction times (RTs) and error rates separately for shifts and repetitions for the remaining five blocks. In all analyses reported in this article, the adopted significance level was $\alpha = 0.05$. For significant effects, individual P values are not reported.

RT data

Figure 1 depicts mean RTs separately for the three Information conditions as a function of Task type and Block. A 3 (Information condition) × 5 (Block) × 2 (Task type) mixed-factor analysis of variance (ANOVA) revealed significant effects for the factors Information condition, $F(2,57) = 12.32$, $\mathrm{MSE} = 183{,}712.9$, Block, $F(4,228) = 38.32$, $\mathrm{MSE} = 17{,}800.4$ and Task type, $F(1,57) = 8.17$, $\mathrm{MSE} = 14{,}237.0$. Furthermore, there were highly significant interactions between Information condition and Block, $F(8,228) = 14.71$, $\mathrm{MSE} = 17{,}800.4$, Information condition and Task type, $F(2,57) = 6.35$, $\mathrm{MSE} = 14{,}237.0$, and Block and Task type, $F(4,228) = 2.54$, $\mathrm{MSE} = 6{,}677.0$, which were qualified by the triple interaction between Information condition, Block, and Task type, $F(8,228) = 3.13$, $\mathrm{MSE} = 6{,}677.0$. This latter triple interaction reflects the fact that participants in the Early Information condition exhibited switch costs throughout Blocks 2–6, whereas switch costs were completely absent in the Uninformed condition and arose in the Late Information condition in Block 5 after the introduction of the task rules.

Planned comparisons between task repetitions and task shifts confirmed this interpretation of the triple interaction. They revealed that in the Early Information condition, repetitions were faster than shifts throughout Blocks 3–6 [Block 2: $P = 0.43$, $F < 1$; Block 3: $F(1,57) = 37.8$, $\mathrm{MSE} = 11{,}018.6$; Block 4: $F(1,57) = 9.89$, $\mathrm{MSE} = 3{,}810.66$; Block 5: $F(1,57) = 17.89$, $\mathrm{MSE} = 1{,}651.87$; Block 6: $F(1,57) = 5.04$, $\mathrm{MSE} = 1{,}493.13$]. The Late Information condition yielded no significant differences in Block 2–4 [Blocks 2 and 3: $P > 0.9$, $F < 1$; Block 4: $P = 0.19$, $F(1,57) = 1.74$]. In Block 5, however, the introduction of task rules led repetitions to be answered significantly faster than shifts, $F(1,57) = 9.73$, $\mathrm{MSE} = 1{,}651.87$. In Block 6, switch costs again disappeared ($P = 0.33$, $F < 1$). And finally in the Uninformed condition shifts and repetitions did not differ in any of the five blocks (all $P > 0.4$, all $F < 1$).

Error rates

Figure 2 contains mean error rates as a function of Task type and Block in the three Information conditions. A 3

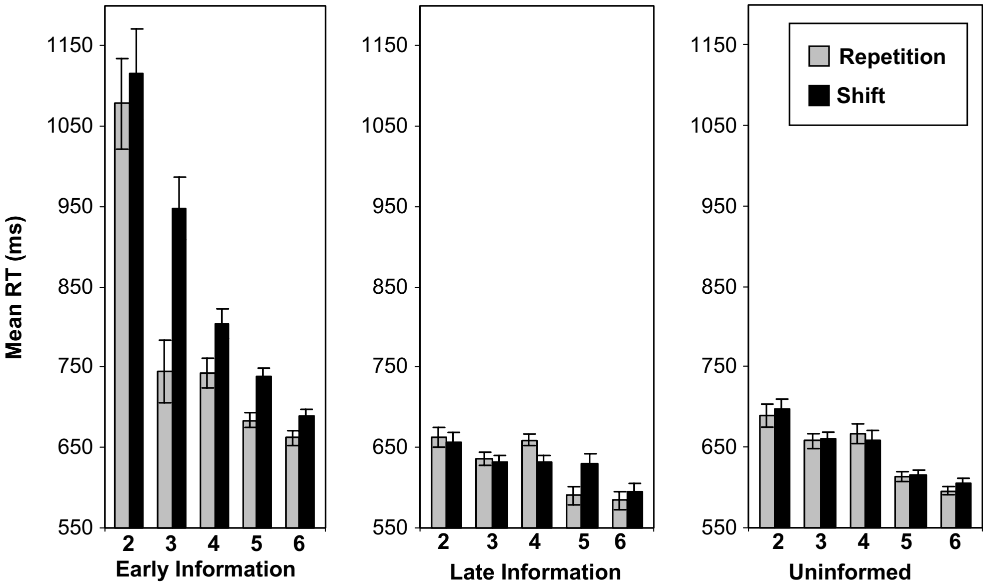

Fig. 1 Mean RT as a function of Task type and Block in the three Information conditions in Experiment 1. Error bars represent 95% within-participant confidence intervals based on the corresponding shift-repetition comparison (Loftus & Masson, 1994)

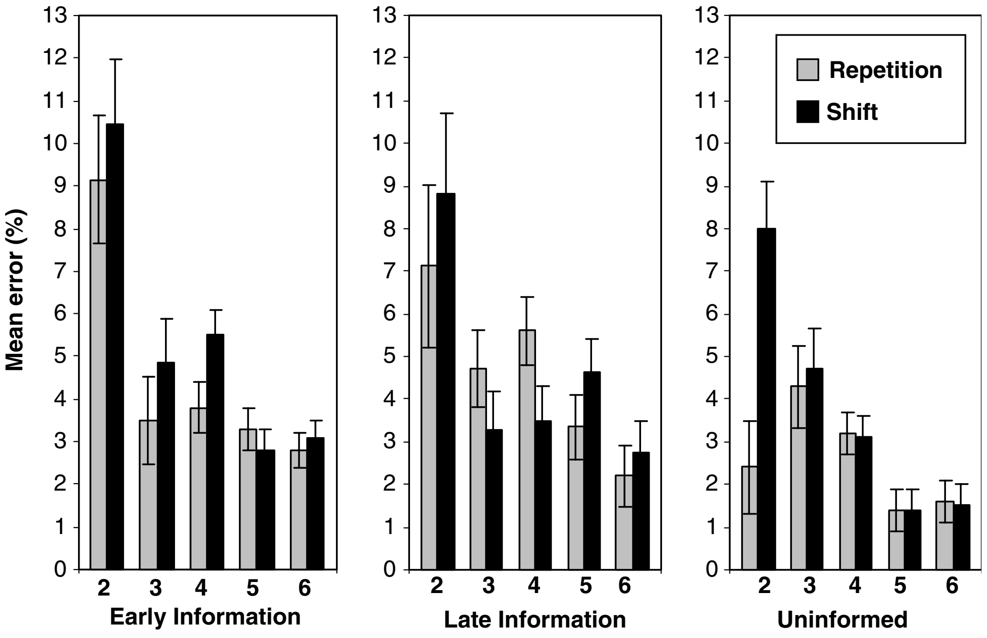

Fig. 2 Mean error percentage as a function of Task type and Block in the three Information conditions in Experiment 1. Error bars represent 95% within-participant confidence intervals based on the corresponding shift-repetition comparison (Loftus & Masson, 1994)

(Information condition) × 5 (Block) × 2 (Task type) mixed-factor ANOVA yielded a significant main effect of the factor Block, $F(4,228)=20.04$, MSE = 25.94, a marginally significant effect of Task type, $F(1,57)=3.74$, MSE = 17.10, $P=0.057$, and a significant interaction Block × Task type, $F(4,228)=2.46$, MSE = 18.66. No further interaction proved reliable (all $P>0.14$). Error rates decreased with increasing practice and were smaller for repetition trials than for shift trials (3.9 vs. 4.5%). The Block × Task type interaction is due to an increase of error rates for shifts that occurred only in Block 2. In this block, participants produced significantly more errors in shift trials than in repetition trials, $F(1,57)=4.91$, MSE = 49.43, whereas in all other blocks error rate did not differ between shifts and repetitions (all $P>0.5$). In other words, in Block 2 error costs appeared even in the Late and Uninformed conditions (without task rule information). We assume that these error costs occur for different reasons in the Early and Late/Uninformed conditions, respectively. In the Early condition the error costs might actually represent difficulties when switching from one task rule to the other. However, in the Late and Uninformed conditions participants do not have any task rule information. The reason why they make more errors on task switch trials as compared to task repetitions is probably due to the fact that in Block 2, these participants have to learn that a color switch (which represents a task switch) does not automatically imply a response switch (note that in the preceding Block 1 participants could simply answer the task by pressing the left key whenever a red stimulus appeared and press the right key whenever a green stimulus appeared).

Overall, the results of Experiment 1 are clear cut: first of all, participants in the Early Information condition who received task rule information at the beginning of the experimental session exhibited switch costs as soon as six different stimuli are introduced (Block 3). Even though the Uninformed condition confirms that it was obviously possible to accomplish the given tasks by simply applying single S–R mappings, the knowledge about the task rules appears to keep participants from doing so. Second, the significant switch costs in Block 5 in the Late Information condition shows that even after having practiced the use of direct S–R mappings, the introduction of the task rules led participants to use these task rules instead of further applying direct S–R mappings. Third, relying on task rules—as did participants in the Early Information condition—was accompanied by dramatic overall costs. Participants in this condition needed generally more time to accomplish the tasks than did participants in the Late and the Uninformed conditions.[1] This is a somewhat surprising result because this finding suggests that using task rules is obviously a rather inefficient strategy. To rule out the possibility that these overall costs in the Early group were due to the confusion of the participants being indecisive whether to base their performance on single S–R mappings or task rules, we ran a simple control experiment with 20 participants. Like in standard task switching experiments, both tasks with all eight stimuli were introduced at once. After three blocks of the same length as the experimental Blocks 4–6 of the

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[1] We can rule out that this effect is simply due to some unusually slow participants in the Early group. Excluding the five slowest participants from the analysis does not alter the results: the main effect of the factor Information condition remains significant as do all other main effects and interactions.

present experiment, participants had just reached the RT level of Block 4 in the Early Information condition with switch costs being present in all blocks. Hence, we can rule out that the overall RT disadvantage in the Early group was due to the specifics of the augmenting S–R presentation.

Results of the Late and Uninformed groups show that participants in the current experiment had no difficulty to rely their task performance on direct S–R mappings. They could easily memorize the eight S–R mappings whereas the application of the task rules in the Early Information condition obviously was more complicated producing slower latencies. However, this difference makes it even more surprising that participants in the Early Information condition did not use the S–R mappings but instead followed the instructions and relied their performance on these task rules. One possible explanation is that participants in the Early Information condition adopted the task rules at the beginning of the experiment because they did not know in advance how many different stimuli would be presented over the course of the experiment (the participants in the other groups did not have this information either, but they had no choice than relying on the S–R mappings). The second surprising result is that participants in the Late and the Uniformed conditions had virtually no problems in learning the eight different S–R mappings. Probably, the short stimulus words we used in the current experiment were too easy, thereby giving the S–R strategy a big advantage over the task rule. In Experiment 2, we therefore used longer words with four syllables each in order to make the S–R mappings harder to learn. The use of longer words should increase the memory load in the Late and the Uniformed conditions and thereby make the task more difficult in these groups (e.g., Baddeley, Thomson & Buchanan, 1975). The Early Information condition, however, should not be affected by this manipulation.

Experiment 2

Method

Participants

Sixty students (41 females, mean age 21.78, SD 1.89, range 18–28) from the Dresden University of Technology participated for a small financial reward (€ 2). Twenty participants were assigned to each of the three experimental conditions, respectively.

Stimuli and procedure

The procedure of Experiment 2 was exactly the same as that of Experiment 1 except for the stimuli used. This time we used the four German nouns written in red (“Bettvorleger, Inselgruppe, Suppenlöffel, Eisenstange”) and four German nouns written in green (“Rabenkrähe, Ameisenbär, Hausaufgabe, Uhrenmacher”). All words consisted of four syllables; participants again either had to decide whether the word started with a consonant or a vowel (red words) or whether a word was an animal or not (green words). Again consonant and animal were assigned to the left response key and vowel and no animal were assigned to the right key.

Results and discussion

The data analytic strategy follows Experiment 1. Again, individual median RTs and error rates of each factor combination for each participant were computed and entered into analysis.

RT data

Figure 3 depicts mean RTs separately for the three Information conditions as a function of Task type and Block. A 3 (Information condition) × 5 (Block) × 2 (Task type) mixed-factors ANOVA revealed significant main effects for the factors Block, $F(4,228) = 21.63$, MSE = 19,416.1, and Task type, $F(1,57) = 18.1$, MSE = 8,345.0. In contrast to Experiment 1, the main effect of Information condition did not prove reliable ($P = 0.22$, $F = 1.54$). Furthermore, there were highly significant interactions between Information condition and Block, $F(8,228) = 4.03$, MSE = 19,416.1, Information condition and Task type, $F(2,57) = 4.75$, MSE = 8,345.0, and Block and Task type, $F(4,228) = 3.82$, MSE = 4,856.3. The triple interaction was not significant ($P > 0.2$, $F < 1.5$).

Planned comparisons between task repetitions and task shifts revealed that in the Early Information condition, repetitions were faster than shifts throughout Blocks 2–5 (Block 2: $F(1,57) = 7.76$, MSE = 18,238.6; Block 3: $F(1,57) = 14.54$, MSE = 4,565.76; Block 4: $F(1,57) = 17.36$, MSE = 2,210.38; Block 5: $F(1,57) = 10.31$, MSE = 2,206.26). In Block 6, however, switch costs were no longer reliable ($P > 0.15$, $F < 2$). In the Late Information condition, switch costs again were not significant throughout Blocks 2–4 (all $P > 0.4$, all $F < 1$). After the introduction of the task rules in Block 5, however, repetitions were answered significantly faster than shifts, $F(1,57) = 17.0$, MSE = 2,206.26. In Block 6 switch costs were no longer present ($P = 0.82$, $F < 1$). And finally in the Uninformed condition, shifts and repetitions did not differ in any of the five blocks (all $P > 0.18$, all $F < 1.8$).

Error rates

Figure 4 contains mean error rates as a function of Task type and Block in the three Information conditions. A 3 (Information condition) × 5 (Block) × 2 (Task type)

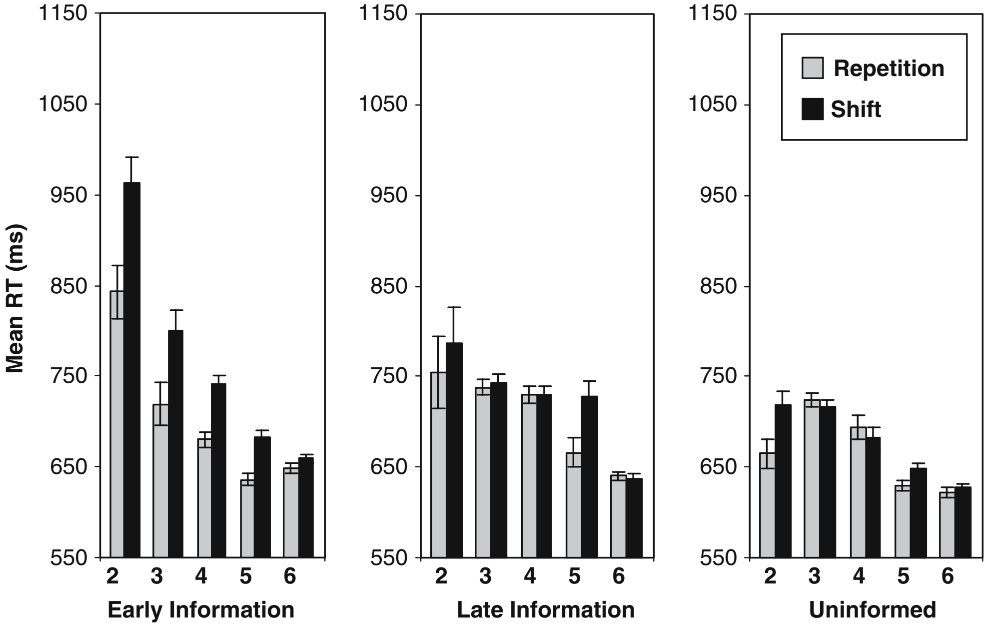

Fig. 3 Mean RT as a function of Task type and Block in the three Information conditions in Experiment 2. Error bars represent 95% within-participant confidence intervals based on the corresponding shift-repetition comparison (Loftus & Masson, 1994)

mixed-factors ANOVA yielded a significant main effect of the factor Block, $F(4,228)=13.18$, $MSE=28.55$, reflecting the fact that error rates generally decreased over the course of the experiment. The factor Information condition ($P>0.6$, $F<1$) and Task type ($P>0.1$, $F<2.5$) did not prove reliable. Furthermore, the interaction of Block and Task type was significant, $F(4,228)=3.52$, $MSE=18.71$. No further interaction reached statistical significance (all $P>0.34$, all $F<1.1$). Planned comparisons of shifts and repetitions for the different Blocks revealed a significant effect in Block 2, $F(1,57)=4.75$, $MSE=51.19$, but not so in Blocks 3 and 4 (both $P>0.16$). In Blocks 5 and 6, the difference between shift and repetition was marginally significant, $F(1,57)=3.75$, $MSE=9.08$, $P=0.057$ and $F(1,57)=3.73$, $MSE=8.84$, $P=0.058$, respectively.

Thus, results of Experiment 2 replicate the findings of Experiment 1: Again, participants in the Early Information condition showed significant switch costs, this time even from the very beginning in Block 2 in which only four different stimuli had to be processed. And again, in the Late Information condition direct S–R mappings were applied until the introduction of the task rules after Block 4. Consequently, in Block 5 we found again significant switch costs suggesting that participants actually used the task rules to perform the task at

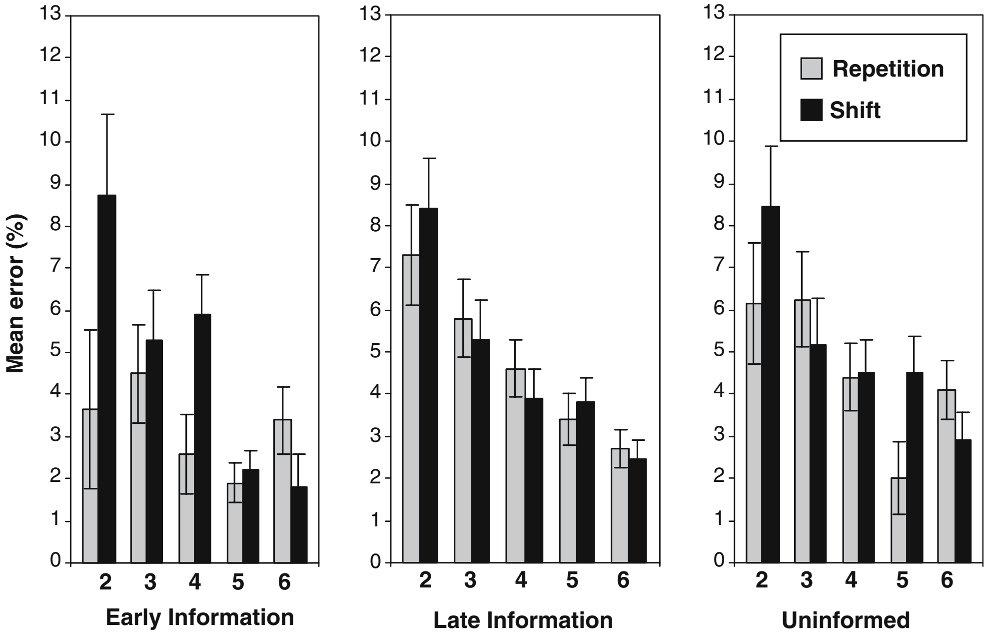

Fig. 4 Mean error percentage as a function of Task type and Block in the three Information conditions in Experiment 2. Error bars represent 95% within-participant confidence intervals based on the corresponding shift-repetition comparison (Loftus & Masson, 1994)

least in this block. And finally, in the Uninformed condition, switch costs never occurred. Participants in this group obviously did not have any problems to learn and apply the eight different S–R mappings even with longer stimuli. They performed the tasks just as fast and accurate as participants in the other conditions. The results of Experiment 2 differ in two important aspects from those of Experiment 1. First of all, as expected, the overall costs of the Early Information group in Experiment 1 disappeared in Experiment 2. This is obviously due to the longer stimuli used in Experiment 2. Participants in the Early Information condition descriptively performed faster than those in Experiment 1. One possible reason could be that it made intuitively more sense to use a rather complicated rule for longer stimuli than for short stimuli that are easy to memorize anyway. In other words, participants in Experiment 2 might therefore have been more motivated to use the task rules from the very beginning in the Early Information condition whereas participants in Experiment 1 were hesitant to use the task rule resulting in the observed overall cost. And participants in the Late and the Uninformed conditions performed slower with longer stimuli, which makes sense because longer stimuli obviously impose a higher workload than short stimuli. The second difference concerns the absence of switch costs in Block 6 in the Early Information condition. It is not quite clear why participants shift from rule-based task processing to the application of direct S–R mappings in the last Block. In "normal" task switching experiments, switch costs do not disappear with practice. The only explanation we can come up with is that the successive introduction of the single stimuli led participants to not only learn the task rules but also the direct S–R mappings which might then, after a long period of practice in Block 6, be used to accomplish the task (e.g., Arrington & Logan, 2004). However, in Experiment 1 switch costs remained stable in the Early Information condition until the end.

General discussion

The experiments presented in this article revealed three main findings. First of all, participants in the Early Information condition produced switch costs from the beginning albeit the task procedure, that is, the pair-wise introduction of task stimuli, which suggested the learning and application of direct S–R mappings. Second, even when participants had already learned and successfully applied direct S–R mappings, as was the case in the Late Information condition, switch costs emerged as soon as the task rules were explained to the participants. Note that participants in this group were only casually informed about the task rule without any direct demand to actually use the task rules. Furthermore, nearly all of the participants in the Late Information condition reported in a post-experimental interview that they had *not* intentionally used the task rule to accomplish the task as soon as they became aware of. This finding suggests that the task rules probably were applied automatically (see also Heuer, Schmidtke & Kleinsorge, 2001; Koch, 2005)). And third, the results of the Uninformed condition show that participants in the current experiments were able to memorize and use eight different S–R mappings successfully. Participants in this condition did not actually switch between different task rules (they were not aware of the underlying task rules and were accordingly not able to name these rules in the post-experimental interview) and consequently did not produce any switch costs. This latter result might serve to explain findings from primate studies showing that monkeys in contrast to a human control group were able to switch without a cost between different tasks (Stoet & Snyder, 2003). Probably, however, monkeys did not actually switch between different task rules but instead learned the specific S–R mappings. And using direct S-R mappings does not result in switch costs as our uninformed group shows.

In the Introduction, we raised the question why switch costs occur at all even though in most task switching experiments the number of S–R mappings allows for directly memorizing the response to a corresponding stimulus. Results of the Early Information condition show that even a pair-wise introduction of task stimuli—a procedure that at least implicitly invites participants to learn and apply direct S–R mappings—still results in reliable switch costs. And even when participants already had learned the S–R mappings, as was the case in the Late information condition, they were not able to refrain from using the task rule as soon as it got introduced. At first glance these results seem to fit with the episodic retrieval hypothesis mentioned in the Introduction (Allport & Wylie, 2000; Wylie & Allport, 2000; Hommel et al., 2000; Waszak et al., 2003). The presentation of the task rule at the beginning of the experiment in the Early Information group binds color (here: red and green) and task (consonant/vowel; animal/no animal) together. Any successive new stimulus contains one already known feature, namely the color green or red. Results suggest that hereby any newly introduced stimulus is automatically integrated into the color matching task set. This integration of a new stimulus into an already existing task set seems to be stronger than the ability to use direct S–R information. This is even more surprising if we take into account that in our experiments, in contrast to most task switching experiments (but see Dreisbach et al., 2002, Experiment 3; Ruthruff et al., 2001 for an exception), completely disambiguated stimuli were used. In other words, each particular stimulus was associated with one response such that the color was a completely unnecessary feature to accomplish the task. Still, switch costs in the Early Information condition occurred throughout the experimental blocks.

And what happened in the Late Information condition? Obviously participants in this group already had successfully learned and applied the direct S–R mappings. How come the introduction of the task rule in the middle of the experiment leads to switch costs right afterwards? Remember that participants in the Late and Uninformed conditions also received colored stimuli. The color in these groups, however, was a completely useless but salient stimulus feature. Presumably, introducing the task rules after Block 4 in the Late Information condition finally made this salient color feature informative such that in the upcoming block this color feature now automatically triggered the corresponding task set resulting in the observed switch costs. So far, however, this does not explain why switch costs occurred in Block 5 after the introduction of the task rules but no general RT increase. The data suggest that the task rule, i.e., the color of the stimulus in Block 5 only served as *additional* evidence for generating the correct response. This means, the stimulus already triggered the correct response (see also Pashler & Baylis, 1991, for the locus of practice effects in speeded-choice tasks), and if the stimulus belonged to the same task set (color) as the preceding one, the already activated task set facilitated this process. If the stimulus belonged to a different task set (color), it also directly triggered the response but did not gain additional activation of an already activated task set. This interpretation is in line with recent findings from Logan and colleagues (Arrington & Logan, 2004; Logan & Bundesen, 2003) who showed that cue alternations, that is, a change of the feature that announces a specific task, incur costs that exceed the costs of task switches. The authors went even further and argued that switch costs could generally be attributed to cue switches (instead of task switches). Applied to our paradigm, the color represents the (simultaneous) cue. And this cue incurs a cost only if it is informative to the participant as is the case in the Early Information condition and in the Late Information condition after the introduction of the task rule. Future research is necessary to clarify whether task rule information is always dominant and overrules even already learned S–R mappings or whether it depends on the salience of the feature that distinguishes one task from the other.

The experiments presented here also fit into another line of task switching research dealing with context effects on switch costs. Instead of analyzing effects of transitions of single tasks, this line of research is interested in the influence of global determinants on switch costs (cf. Kleinsorge, 2003). Such global determinants are for example the number of tasks in a given experimental block (e.g., Hübner, Futterer & Steinhauser, 2001), attention strategies like speed versus accuracy instructions (Gopher, Armony & Greenshpan, 2000) or the organizational structure of the task representation (e.g., Kleinsorge & Heuer, 1999; Kleinsorge, Heuer, & Schmidtke, 2004). This latter determinant, namely the role of the task representation, for the occurrence and amount of switch costs is very close to the research presented in this article. What our data show is that switch costs only occur when the underlying S–R mappings are represented as task sets. Without the representation of these mappings as task set, no switch costs occur. The performance, however, at least with the disambiguated stimuli we used, seems to be even more efficient without any task set representation.

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