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Implicit Task Sets in Task Switching?

Gesine Dreisbach and Thomas Goschke
Dresden University of Technology

Hilde Haider
University of Cologne

In 2 experiments, the authors compare stimulus-based versus task-rule-based task performance. Participants practiced 8 stimulus–response mappings either with or without knowledge about 2 underlying task sets. After practice, 2 transfer blocks with 8 new stimuli were presented. Results show that rule knowledge leads to significant switch and transfer costs, whereas without rule knowledge neither switch nor transfer costs occur. However, significant Task Type × Response Type interactions occurred in both conditions. In a second experiment including only the no rule condition, half of the stimulus–response mappings in the transfer blocks were incongruent to the underlying task rule. Slower response times for these incongruent stimuli as compared with congruent stimuli and the absence of switch costs suggest that participants acquired (presumably implicit) knowledge about 4 different stimulus–response categories.

Keywords: task switching, stimulus response mapping, hidden covariation learning

To study processes of cognitive control, researchers have widely used the task-switching paradigm in experimental cognitive psychology since its rediscovery by Allport and colleagues about 10 years ago (D. A. Allport, Styles, & Hsieh, 1994). In this paradigm, participants are asked to switch forth and back between two or more simple cognitive tasks (e.g., judging whether a letter is a consonant or a vowel or whether a digit is odd or even). The common finding is that performance is better whenever a task is repeated (two letter judgments in a row) as compared with performance when the task changes (one letter task followed by a digit task). Whether these *switch costs* should be interpreted rather as a *repetition benefit* (A. Allport & Wylie, 2000; Altmann, 2004a, 2004b; Dreisbach, Haider, & Kluwe, 2002; Dreisbach & Haider, 2006; Koch, 2001, 2005; Logan & Bundesen, 2003; Ruthruff, Remington, & Johnston, 2001; Sohn & Anderson, 2001; Sohn & Carlson, 2000; Wylie & Allport, 2000) or whether switch costs at least in part reflect the time that is needed to reconfigure the cognitive system to the changed task demands is still subject to debate (Goschke, 2000; Logan & Gordon, 2001; Meiran, 1996; 2000; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001).

A closer look at the specific tasks and stimuli used in standard task-switching experiments, however, brings up one question that may be even more crucial: Why at all do participants switch between tasks in the first place (and consequently produce switch costs) instead of learning and using direct stimulus–response (S-R) mappings (and consequently produce no switch costs)? Recent work by Logan and colleagues (Logan & Bundesen, 2003; Schneider & Logan, 2005) suggested that participants might adopt a compound-stimulus strategy when switching between simple tasks. According to this view, the repetition of the task cue that usually goes along with a task repetition accounts for the observed switch costs (but see also Mayr & Kliegl, 2003). To return to the question raised above, even if participants apply an S-R strategy when switching between tasks, switch costs (or rather cue repetition benefits) still occur as a result of cue encoding. This, however, may depend on the specific task procedure. In recent studies from our labs (Dreisbach, Goschke, & Haider, 2006), we could show that the S-R strategy does not produce switch costs if participants are not informed about the meaning of the task cues: In that design (which is very similar to the one used in this article), all participants received eight different stimuli from which half were presented consistently in red whereas the other half of the stimuli were presented consistently in green. The only experimental manipulation was foreknowledge about two underlying task rules. In the task-rule condition, participants were informed about the underlying task rules. That is, they were told that they were required to decide whether a stimulus (a word) written in red started with a consonant or a vowel and whether a word written in green represented an animal. By contrast, in the S-R condition, participants did not receive any information about the underlying task rules. They had to learn the S-R mappings directly without applying any categorization rules. It turned out that the occurrence of switch costs depended on the availability of task rules. In the S-R condition, without any task-rule information, no difference between task shifts and task repetitions (which corresponded to color shifts and color repetitions) occurred. That is, as long as the stimulus color was not informative for the participants, it did not interfere with task performance even though color consistently covaried with the (task-rule dependent) stimulus features. However, a yet unanswered question is whether this finding means that participants in the S-R condition did not acquire associations between color and other more subtle stimulus and response features.

Gesine Dreisbach and Thomas Goschke, Institute of Psychology I, Dresden University of Technology, Dresden, Germany; Hilde Haider, Institute for Psychology, University of Cologne, Cologne, Germany.

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Correspondence concerning this article should be addressed to Gesine Dreisbach, Institute of Psychology I, Dresden University of Technology, Dresden, 01062 Germany. E-mail: dreisbach@psychomail.tu-dresden.de

The goal of the current work therefore was to investigate whether practicing S-R mappings with two underlying task rules leads to implicit rule abstraction. That is, whereas Logan and colleagues (Logan & Bundesen, 2003; Schneider & Logan, 2005) showed that rule-based learning can turn into S-R-based processing, we will take the opposite approach by showing that S-R-based learning can turn into rule-based processing. More precisely, the purpose of the current experiments was to examine whether participants in the above mentioned paradigm (Dreisbach et al., 2006) learn an association between the stimulus color and the consistently covarying stimulus and response features. Preliminary evidence for this assumption comes from at least three research areas: (a) response alternation effects (e.g., Kleinsorge & Heuer, 2000; Marczinski, Milliken, & Nelson, 2003; Notebaert & Soetens, 2003), (b) hidden covariation detection (e.g., Lewicki, 1986; Lewicki, Hill, & Czyzewska, 1994), and (c) episodic binding (e.g., Hommel, 2004, 2005; Waszak, Hommel, & Allport, 2003). Before we introduce our experimental approach, we will briefly describe how these research lines relate to our assumptions.

Response Alternation Effects

The response alternation effect refers to the interaction of stimulus feature change (e.g., color) and response change. For example, in task switching a task switch along with a response switch is usually faster than a task switch along with a response repetition. Likewise, a task repetition associated with a response repetition is faster than a task repetition along with a response switch (Kleinsorge, 1999). Kleinsorge (1999) could show that this Response × Stimulus interaction even occurred when irrelevant stimulus features changed. Kleinsorge and Heuer (2000) therefore concluded that any feature change, be it task relevant or not, might enter task representation and bias the response system toward a change. Moreover, even simple single S-R mappings can produce response alternation effects: Marczinski, Milliken, and Nelson (2003) mapped four colors to two different response keys and found—aside from the rather trivial effect that immediate repetitions of the same stimulus produced fastest responses—that stimulus switches requiring a response switch were faster than stimulus switches requiring a response repetition. Comparable results have been reported earlier (Campbell & Proctor, 1993; Pashler & Baylis, 1991). Likewise, Notebaert and Soetens (2003) provided evidence that these response alternation effects in simple S-R tasks even occur when irrelevant stimulus features change. This latter result suggests that participants in our S-R condition might associate the irrelevant color feature with response features. Therefore, one aim of the current study was to look at possible Color Repetition × Response Alternation interactions in the above mentioned paradigm. If we will find evidence for an integration of color and response features we will then, in a further step, investigate whether other stimulus features that covaried with the color feature were also associated with response features. This latter assumption directly leads to the second relevant research area.

Hidden Covariation Detection

To date, the results on hidden covariation learning are highly controversial. Lewicki and colleagues (e.g., Lewicki, 1986; Lewicki et al., 1994) repeatedly showed that participants integrate consistently covarying but irrelevant stimulus features for later inferences on different stimuli that share these irrelevant stimulus features. Others, however, were not always able to replicate the results (e.g., Hendrickx, De Houwer, Baeyens, Eelen, & Van Avermaet, 1997; but see also the reply by Lewicki, Hill, & Czyzewska, 1997). Applied to our S-R paradigm, the question therefore is whether participants will acquire abstract knowledge about the two underlying task rules. This assumption at first glance seems to contradict most of the assumptions held in the field of implicit learning that deny the implicit acquisition of rule knowledge (e.g., Boyer, Destrebecqz, & Cleeremans, 2005; Jiménez, Mendez, & Cleeremans, 1996; Stadler, 1992). However, rule knowledge in the research tradition of implicit sequence learning differs in important aspects from rule knowledge in our paradigm. Whereas in sequence learning the rule knowledge leads to more or less valid implicit expectations of the upcoming stimulus and response, thereby accelerating task processing, rule knowledge in our paradigm would lead to stronger and easier to memorize associations between stimulus and response. That is, with our paradigm we investigate whether covariation learning is possible between a salient color feature and more subtle graphemic and semantic stimulus features.

Episodic Feature Binding

According to this view, any task execution leads to an episodic binding between the stimulus features and the corresponding response (Hommel, 2004). This episode is then automatically retrieved when the stimulus is presented again, resulting in a benefit if the task does not change but resulting in a cost if a different task has to be carried out on this stimulus. For example, Waszak and colleagues (Waszak, Hommel, & Allport, 2003) asked participants to switch between picture naming and word reading with incongruent picture-word stimuli. They observed higher switch costs for the word reading task when the word had to be picture named before as compared with a word that had never been presented as a word. What is most important, this effect even generalizes to semantically related stimuli (Waszak, Hommel, & Allport, 2004). To give an example, having to name a picture of a chair would later on impair reading performance of the word *sofa*. Related to our approach, one might therefore expect that learning S-R bindings that follow hidden rules might generalize to other words that share these rule dependent stimulus features.

To investigate whether participants in the S-R condition implicitly acquired abstract feature knowledge, we altered the paradigm used previously (Dreisbach et al., 2006): As in the former experiments, eight words mapped to two response keys were introduced in steps of two per block either with or without foreknowledge about the underlying task rules.[1] In the current experiment, however, participants received two additional transfer blocks in which the old stimuli were replaced by eight new stimuli. We expected to replicate our previous findings, that is, (a) reliable switch costs throughout training and transfer blocks in the task rule condition and (b) no switch costs in the S-R condition. As for the transfer blocks, we expected that if participants in the S-R group acquired

[1] The stepwise introduction of the stimuli was used to reduce working memory load in the S-R condition.

some kind of implicit knowledge about abstract stimulus features, participants in this group should not show any difficulties to process the transfer stimuli. That is, participants in the S-R condition should be able to generalize this knowledge to the transfer stimuli. If, however, participants base their performance solely on specific S-R mappings, they would have to learn eight new stimuli from scratch and consequently should be impaired in the transfer blocks. In the task-rule condition, we expected that if participants practice the application of the task rule in the training blocks, then we should find no performance deficit in the transfer blocks (because the task rules do not change). However, this assumption holds that the practice effects can be attributed to the improved rule usage itself. Alternatively, according to Pashler and Baylis (1991), practice effects rather affect the response selection stage, that is, practice strengthens the link between a specific category representation and a spatially defined response. If this assumption holds, we should find a performance deficit in the transfer blocks in the task-rule condition.

As a second goal, we will look at possible Task Repetition × Response Alternation interactions. A significant Color Repetition × Response Alternation interaction in the S-R group will provide first evidence that at least the color feature in this group got integrated into the task representation (see Notebaert & Soetens, 2003). Likewise, and as derived from the task-switching literature, we expect that participants in the task-rule condition will show a significant Task Repetition × Response Alternation interaction in the training and transfer blocks (see, e.g., Kleinsorge, 1999; Kleinsorge & Heuer, 2000).

Experiment 1

Method

Participants. Fifty students (45 female, 5 male; mean age = 21.84 years, *SD* = 2.89, range = 18–32) from the Dresden University of Technology, Dresden, Germany, participated for a small financial reward (€2; U.S.$2.55). Twenty-five participants were assigned to the two experimental conditions.

Stimuli and procedure. Four German words written in red (*Bett* [bed], *Sieb* [strainer], *Arm* [arm], and *Eis* [ice]) and four words written in green (*Rabe* [raven], *Igel* [hedgehog], *Haus* [house], and *Uhr* [clock]) served as practice stimuli. For transfer stimuli, we used four different German words written in red (*Glas* [glass], *Hose* [pants], *Ofen* [oven], and *Iris* [iris]) and four different words written in green (*Möwe* [seagull], *Esel* [donkey], *Kohl* [cabbage], and *Auto* [car]). Response keys were the two outermost keys on the left and on the right side of the bottom of a computer keyboard. Two words of each color were assigned to the left key ([bed], [strainer], [raven], and [hedgehog]; transfer: [glass], [pants], [seagull], [donkey]); 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 of another 400 ms, the next trial started. Feedback was given only for incorrect responses, in which case the intertrial interval was extended to 2000 ms.

The experiment consisted of six practice blocks and two transfer blocks. 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 eight practice words appeared (see Table 1). After Block 6, the complete set of transfer items was introduced at once. In two further blocks, only these transfer items were presented.

In a given block, each word appeared 10 times, resulting in a block length of 20 (1st block), 40 (2nd block), 60 (3rd block), and 80 (4th, 5th, 6th, 7th, 8th). Target stimuli were presented at random. Stimulus repetitions were allowed but excluded from the analyses (11.3% in Blocks 2–8). Because of the increasing work load on working memory, Blocks 3 and 4 started with 6 practice trials, featuring only the new additional two words that, however, were also excluded from the analysis. Likewise, in the first transfer block (Block 7) each of the eight new stimulus words was presented twice in a row before the random presentation started. These 16 trials were also excluded from the analysis. The number of task switches and task repetitions was counterbalanced across blocks, and this procedure was identical in all conditions. The information was manipulated by the written instructions. Participants in the task-rule condition were 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 repeated only 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 upcoming two blocks. After Block 6, the eight new stimulus words together with the task rules were presented. Participants were told that only these new words would appear in Blocks 7 and 8.

In the S-R 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 S-R mapping of each additional word pair before each block. After Block 4, they were simply told that no further words would be introduced and asked to work through another two blocks. After that, participants received the eight new words and the corresponding response keys. That is, in contrast to the task-rule condition, participants never got any explicit information about the task rules but instead were asked to memorize the S-R mappings directly. Note that participants in this condition also received colored stimuli; the color however was never explicitly mentioned. They were asked at the end of the

Table 1
Order and Number of Words and Corresponding Response Key per Block in Experiment 1

Response key	Block 1	Block 2	Block 3	Blocks 4–6	Blocks 7–8 (transfer)
Stimulus: red; task: consonant–vowel					
left	Bett	Bett	Bett	Bett	Glas
			Sieb	Sieb	Hose[a]
right		Arm	Arm	Arm	Ofen[a]
				Eis	Iris
Stimulus: green; task: animal–no animal					
left		Rabe	Rabe	Rabe	Möwe
				Igel	Esel[a]
right	Haus	Haus	Haus	Haus	Kohl
			Uhr	Uhr	Auto[a]

[a] Stimuli representing the task-rule incongruent items in Experiment 2 that were then mapped to the other response key.

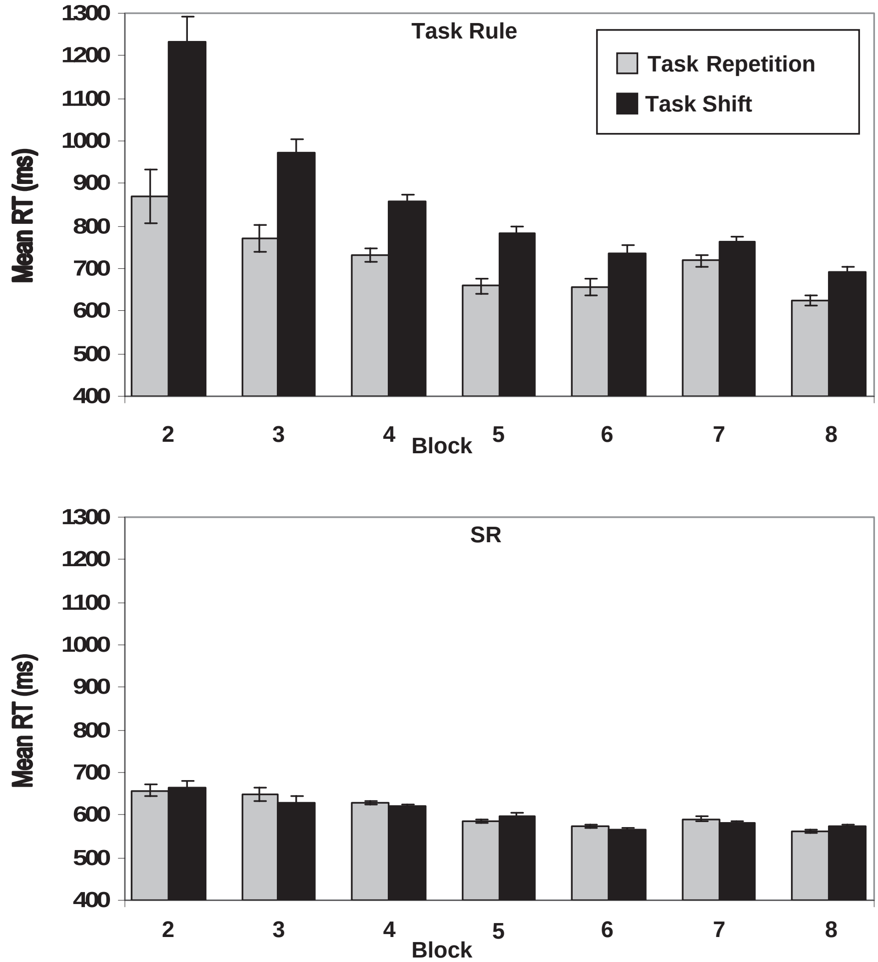

Figure 1. Mean reaction time (RT) as a function of task type and block in the two information conditions in Experiment 1. Error bars represent 95% within-participant confidence intervals based on the corresponding shift–repetition comparison (Loftus & Masson, 1994).

experiment what kind of strategy they had used to remember the words (no one guessed the actual task rules).

Design. A 2 (information condition: task rule, S-R) × 8 (block) × 2 (task type: repetition, shift) × 2 (response type: repetition, shift) mixed-factors design was used. Information condition was manipulated between participants; block, task type, and response type were manipulated within participants. Note that the color of the stimulus indicates the corresponding task only in the task-rule condition. In the S-R condition, a task shift therefore corresponds to a color shift and a task repetition consequently to a color repetition. For reasons of simplicity, we will stay with the term task type (and task repetition vs. task shift) for both information conditions.

Results and Discussion

Incorrect responses and those following an error were excluded from the analysis. Furthermore, Block 1 was excluded from the analysis because in this block only two different stimuli were presented such that a task repetition necessarily always was a stimulus repetition.[2] As stated in the *Method* section, stimulus repetitions were also excluded (11.3%). For each participant, we then computed individual median reaction times (RTs) and error rates separately for shifts and repetitions for the remaining seven blocks. The *Results* section is divided in three parts. First and second, we will report the data collapsed over response repetitions and response shifts separately for the training blocks (Blocks 2 through 6) and the transfer blocks (Blocks 7 and 8). Finally, we will look at response alternation effects in Blocks 5–8. In the text, we will report only those statistics that directly relate to our hypotheses. Detailed statistics are presented in separate tables. In all analyses reported in this article, the adopted significance level was $\alpha = .05$. For significant effects, individual p values are not reported.

RT data. Figure 1 depicts mean RTs separately for the two information conditions as a function of task type in Blocks 2–8. Three features are apparent at first glance: (a) there was a dramatic overall cost in the task-rule condition, (b) task shifts were an-

[2] Mean RTs and error rates in this first block were as follows: for task-rule condition, task repetitions, 853 ms (4.4%), and task shifts, 1,145 ms (8.8%); and for S-R condition: task repetitions 433 ms (4.4%), and task shifts, 452 ms (3.8%). Obviously so, participants in the task-rule condition followed the task rules even when only two stimuli were presented.

swered slower than task repetitions in the task-rule condition but not so in the S-R condition, and (c) the introduction of the transfer items provided a more pronounced RT increase in the task-rule condition than in the S-R condition.

Training. A 2 (information condition) × 5 (Blocks 2–6) × 2 (task type) mixed-factor analysis of variance (ANOVA) substantiated the first two observations with highly significant main effects for the factors information condition, block, and task type (for detailed statistics, see Table 2). Furthermore, all higher order interactions proved reliable. Planned comparisons revealed that switch costs were present in the task-rule condition throughout Blocks 2–6 (Table 3). In the S-R condition, switch costs never were significant (all ps $> .4$, all Fs < 1). Thus, the training results replicated our former findings.

Transfer. To investigate the effects of the introduction of the transfer stimuli, we computed a 2 (information condition) × 3 (Blocks 6–8) × 2 (task type) mixed-factors ANOVA (see Table 4). The main effects information condition, block, and task type proved reliable. Furthermore, the interactions Information Condition × Block, and Information Condition × Task Type, and Task Type × Block were significant. The second order interaction Information Condition × Block × Task Type did not reach significance ($p = .18$). Planned comparisons revealed that switch costs were present in the task-rule condition, $F(1, 24) = 21.55$, $MSE = 7{,}066.40$, but were completely absent in the S-R condition ($p = .95$, $F < 1$). To figure out whether RTs increased with the introduction of transfer items from Block 6 to 7 in the different information conditions, we also conducted planned comparisons. In the task-rule condition, RTs increased significantly, $F(1, 24) = 10.93$, $MSE = 4{,}782.80$, an effect that was far from significance in the S-R condition ($p = .24$, $F = 1.31$). From Block 7 to 8, RTs decreased significantly in the task-rule condition, $F(1, 24) = 47.60$, $MSE = 3{,}550.00$, but not so in the S-R condition ($p = .12$, $F = 2.40$).

Error data. Figure 2 shows mean error rates as a function of task type and block in the two information conditions. Participants obviously made fewer errors with increasing practice and made generally more errors on shift trials as compared with repetition trials (3.81% vs. 2.98%).

Training. A 2 (information condition) × 5 (Blocks 2–6) × 2 (task type) mixed-factor ANOVA confirmed this observation with a significant main effect of the factors block, $F(4, 192) = 15.32$, $MSE = 18.08$, and task type, $F(1, 48) = 10.86$, $MSE = 18.73$, whereas the factor information condition did not prove reliable ($F = 1.70$, $p = .19$). Moreover, the interaction Information Condition × Block was significant, $F(4, 192) = 4.57$, $MSE = 18.08$, and the Block × Task Type interaction just failed to reach the significance level, $F(4, 192) = 2.32$, $MSE = 17.88$, $p = .057$. No further interaction was significant (all ps $> .5$, all Fs < 1).

Transfer. To investigate the effects of the introduction of transfer items on accuracy performance, we conducted a separate 2 (information condition) × 3 (Blocks 6–8) × 2 (task type) mixed-factors ANOVA. Only the interaction Information Condition × Task Type proved reliable, $F(1, 48) = 17.52$, $MSE = 5.76$. The factor block was not significant ($F = 1.70$, $p = .17$). All other main effects and interactions were far from significance (all Fs $<$ 1.10, all ps $> .3$). The interaction was due to the fact that in the task-rule condition task shifts were more error prone than task repetitions, $F(1, 48) = 6.68$, $MSE = 5.57$, whereas the reversed pattern was found in the S-R condition, $F(1, 48) = 11.11$, $MSE =$ 5.75.

Response alternation effects. To examine whether participants in the S-R conditions had acquired associations between color and response features, we entered the response-type factor (repetition, shift) into the analysis. Because of the stepwise introduction of the stimuli, which resulted in an unequal distribution of color and response, only Blocks 5–8 were included in the analysis (in Block 1, the color directly indicated the correct response; in Block 3, two red stimuli but only one green stimulus were mapped to the left key and correspondingly two green stimuli were mapped to the right). Two 4 (block) × 2 (task type) × 2 (response type) repeated measure ANOVAs were conducted separately for the task-rule and the S-R condition (see Table 5 for mean RTs and errors). In the S-R condition, this analysis yielded significant main effects for the factors block, $F(3, 72) = 5.47$, $MSE = 2{,}616.37$, and response

Table 3
Planned Comparisons Between Shift and Repetition RTs per Block in the Task Rule Condition, Experiment 1

Block	*F*(1, 48)	*MSE*
Block 2	31.93	51,382.6
Block 3	31.93	15,863.1
Block 4	65.61	3,101.9
Block 5	42.52	4,363.9
Block 6	14.98	4,924.3

Note. For all blocks, $p < .001$.

Table 2
Statistics of the 2 (Information Condition) × 5 (Blocks 2–6) × 2 (Task Type) ANOVA, Experiment 1, Reaction Time Data

Factor or interaction	*df*	*F* value	*MSE*
Information Condition	1, 48	21.44	255,533.0
Block	4, 192	25.62	30,623.9
Task Type	1, 48	23.02	41,421.3
Information Condition × Block	4, 192	9.78	30,623.9
Information Condition × Task Type	1, 48	24.79	41,421.3
Block × Task Type	4, 192	8.71	9,553.4
Information Condition × Block × Task Type	4, 192	8.01	9,553.4

Note. For all factors and interactions, $p < .001$.

Table 4
Statistics of the 2 (Information Condition) × 3 (Blocks 6–8) × 2 (Task Type) ANOVA, Experiment 1, Error Data

Factor or interaction	*F*	*df*	*MSE*	*p*
Information condition	23.12	1, 48	49,441.85	.001
Block	17.49	2, 96	3,709.98	.001
Task Type	10.49	1, 48	7,066.37	.0021
Information Condition × Block	6.78	2, 96	3,709.98	.002
Information Condition × Task Type	11.06	1, 48	7,066.37	.002
Block × Task Type	3.39	2, 96	1,092.46	.05
Information Condition × Block × Task Type	1.80	2, 96	1,092.46	*ns*

type, $F(1, 24) = 14.09$, $MSE = 1{,}906.49$, whereas the task type was not significant ($F = 2.20$, $p = .14$). What is most important with respect to our hypothesis, the interaction Task Type (which in this condition corresponds to a color repetition) × Response Type proved highly reliable, $F(1, 24) = 23.79$, $MSE = 1{,}197.93$ (see Figure 3, left panel). Furthermore, as a result of practice, block interacted with task type, $F(3, 72) = 3.80$, $MSE = 843.38$, and with Response Type, $F(3, 72) = 4.95$, $MSE = 1{,}036.77$. The higher order interaction did not reach significance ($F = 1.10$, $p = .33$).

The same analysis in the task-rule condition yielded significant effects for the factors block, $F(3, 72) = 8.90$, $MSE = 14{,}332.49$, and task type, $F(1, 24) = 18.77$, $MSE = 35{,}479.58$, whereas response type was not reliable ($F = 1.10$, $p = .28$). As expected, the interaction Task Type × Response Type proved reliable, $F(1, 24) = 48.13$,

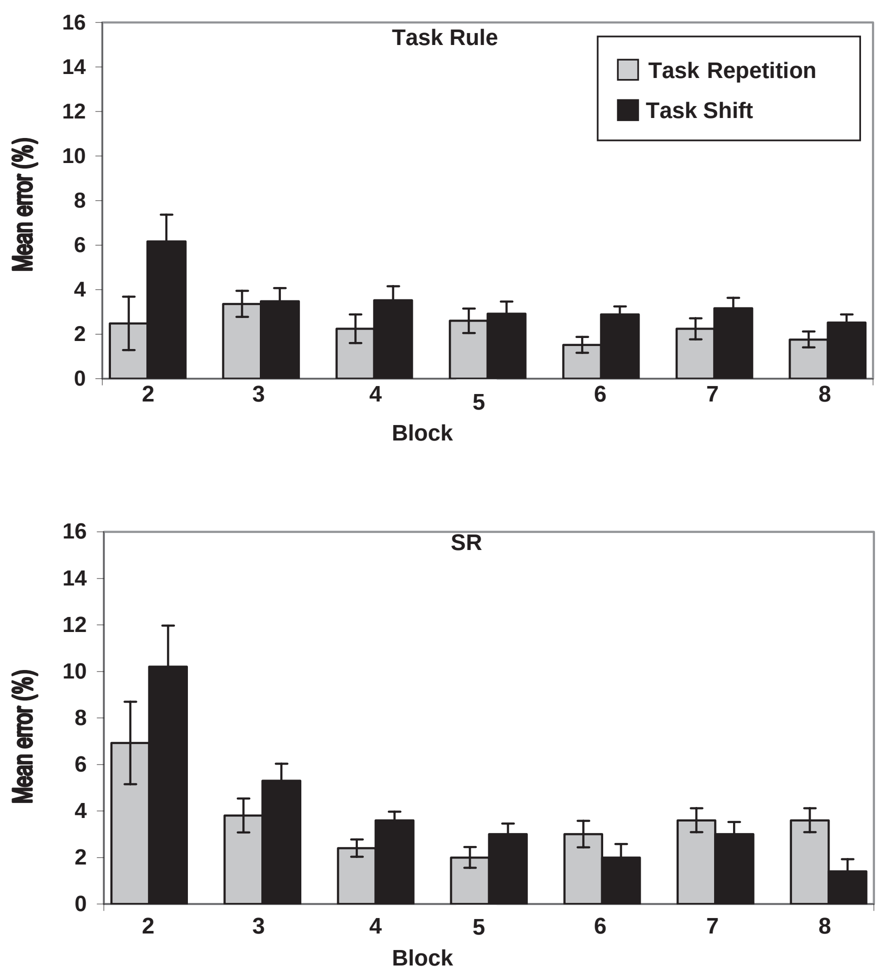

Figure 2. Errors calculated in percentages as a function of task type and block in the two information conditions in Experiment 1. Error bars represent 95% within-participant confidence intervals based on the corresponding shift–repetition comparison (Loftus & Masson, 1994).

Table 5
Mean Reaction Times (RTs) and Error Rates in Blocks 5–8 of Experiment 1

Stimulus	Task rule *M RT*	Task rule *SEM*	Task rule Mean error	Task rule *SEM*	S-R *M RT*	S-R *SEM*	S-R Mean error	S-R *SEM*
Block 5								
Task repetition								
Response repetition	647.32	18.43	2.04	0.60	559.36	11.16	1.84	0.59
Response shift	695.00	25.57	3.48	1.48	607.40	18.72	2.56	1.03
Task shift								
Response repetition	814.96	42.51	3.24	0.98	601.56	16.30	3.80	0.83
Response shift	748.32	33.71	3.00	0.87	596.28	18.02	2.80	0.71
Block 6								
Task repetition								
Response repetition	647.68	22.27	0.44	0.44	570.44	16.32	1.32	0.73
Response shift	665.28	21.96	2.40	0.69	577.16	13.13	4.48	0.93
Task shift								
Response repetition	773.80	39.70	4.20	0.90	578.04	12.68	3.20	0.70
Response shift	700.20	36.16	2.00	0.65	561.36	11.39	1.20	0.44
Block 7								
Task repetition								
Response repetition	676.36	22.63	0.40	0.40	569.04	14.75	2.00	1.00
Response shift	741.24	26.40	3.64	1.15	611.44	13.56	5.04	1.25
Task shift								
Response repetition	787.88	35.77	3.08	0.85	581.92	11.10	2.48	0.77
Response shift	739.60	31.29	3.24	1.00	590.04	10.93	4.04	1.12
Block 8								
Task repetition								
Response repetition	592.84	12.90	1.20	0.44	541.20	11.75	0.80	0.37
Response shift	639.60	15.68	2.28	0.69	577.16	13.04	5.16	1.20
Task shift								
Response repetition	709.64	30.85	2.80	0.77	568.60	11.76	1.40	0.54
Response shift	683.92	27.48	2.40	0.82	580.48	15.27	2.60	0.82

Note. S-R = stimulus–response.

MSE = 4,966.71 (see Figure 3, right panel) as did the interaction Block × Task Type, $F(3, 72) = 4.09$, $MSE = 3{,}147.26$. Other interactions were not reliable (all Fs < 1.80, all ps $> .14$). Figure 3 depicts the interactions Task Type × Response Type in the task rule and S-R condition, respectively. In an overall ANOVA with information condition as between-subjects factor, the interaction Information Condition × Task Type × Response Type also proved highly reliable, $F(1, 48) = 16.62$, $MSE = 3{,}082.30$.

Error rates were also entered into 4 (block) × 2 (task type/color) × 2 (response type) repeated measure ANOVAs separately for the task-rule and the S-R condition. The error data mirrored the RT data (see Table 5). In the S-R condition, only the main effect task type yielded significance, $F(1, 24) = 8.11$, $MSE = 12.57$, whereas block and response type did not (both Fs < 1.9, both ps $> .18$). Again the theoretically important interaction Task Type × Response Type proved reliable, $F(1, 24) = 12.61$, $MSE = 13.40$. All further interactions did not reach significance (all Fs < 1.20, all ps $> .31$). The same analysis in the task-rule condition brought up a significant main effect of response type, $F(1, 24) = 5.13$, $MSE = 37.11$, whereas block and task type were not reliable (both Fs < 1, both ps $> .40$). Again, the interaction Task Type × Response Type was significant, $F(1, 24) = 10.53$, $MSE = 19.68$, as was the interaction Block × Response Type, $F(3, 72) = 4.50$, $MSE = 10.65$.

To summarize, Experiment 1 revealed three main findings: First of all, we replicated the results of our former work (Dreisbach et al., 2006). In the task-rule condition, knowledge about the task rules provoked switch costs accompanied by generally slower task processing, showing that knowledge about the task rule keeps participants from applying direct S-R mappings. In the S-R condition, however, the tasks can be executed just as quickly and accurately without any differences between task shifts and task repetitions.

The second main finding concerns task performance in the first transfer block (Block 7). RTs significantly increased from Block 6 to Block 7 in the task-rule condition but did not do so in the S-R condition.[3] The missing RT increase in the S-R condition gives us a first hint that participants in this condition had acquired some

[3] This increase cannot be attributed to *restart costs* or *reconsideration costs* (see A. Allport & Wylie, 2000; Gopher, Armony, & Greensphan, 2000) because the first trials of the transfer blocks were not entered into the analysis.

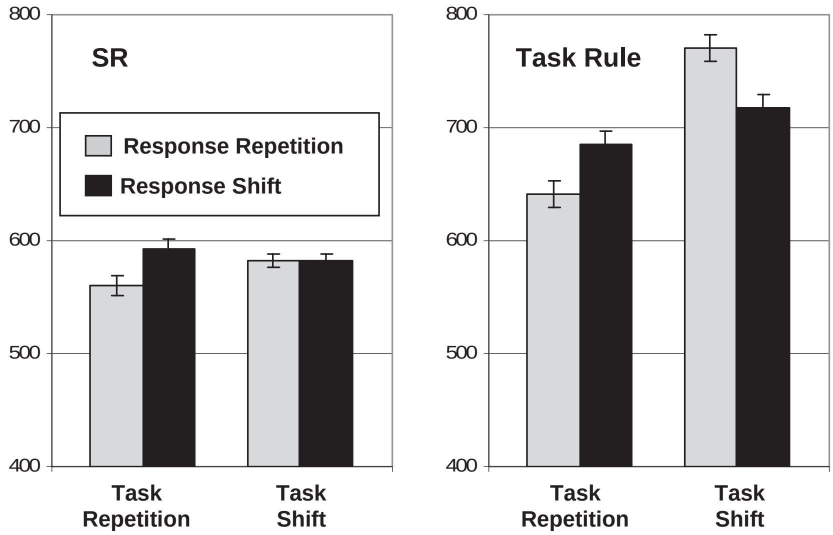

Figure 3. Task Type × Response Type interactions collapsed over Blocks 5–8 in the stimulus–response (S-R; left panel) and task-rule (right panel) condition in Experiment 1. Error bars represent 95% within-participant confidence intervals based on the corresponding response shift–repetition comparison (Loftus & Masson, 1994).

knowledge about the stimulus features in the training that could then be transferred to the new stimuli in Blocks 7 and 8. In contrast, participants in the task-rule condition did not profit from having practiced and used the task rules from the very beginning of the experiment. This finding suggests that the practice effects observed throughout the training blocks were at least in part stimulus specific and thereby not directly available for generalization. Receiving new items in Block 7 requires the integration of these new stimuli into the existing tasks sets (Mayr & Bryck, 2005, see also Waszak, Hommel, & Allport, 2003). This integration appears to be a time consuming process. Moreover, having practiced the use of task rules in Blocks 1–6 primarily strengthened the link between specific category representations and spatially defined responses and is therefore not directly transferable to new stimuli (Pashler & Baylis, 1991). However, it is important to note that the RT increase in the first transfer block in the task-rule condition might not have been detected if the block length would have been extended because in the second transfer block RTs are already faster than in Block 6. That is, the effect obviously depends on the specific time window after the introduction of the transfer stimuli we are looking at.[4] However, compared with the S-R condition we clearly found a difference.

Third, the significant interaction Task Type × Response Type in the S-R group clearly shows that participants in the S-R condition integrated the irrelevant color feature with response features. So far, we can only speculate about the level on which this integration of the color feature occurred. It might be that a color switch, which represents a salient feature switch in this paradigm, biased the system in an unspecific manner toward a change (see, e.g., Kleinsorge, 1999). Even though this interpretation also states that color is integrated into task processing (at the response level), it obviously does not necessarily imply that participants acquired any further presumably implicit knowledge about other consistently covarying stimulus features. However, along with the observed null effect in the transfer blocks, the results support our assumption that participants in the S-R condition actually acquired knowledge about stimulus and response features in the training blocks that could be transferred to new stimuli. However, before further discussing this result, it is important to exclude one alternative explanation for the observed transfer effect (or rather the lack thereof) in the S-R condition. It may be that we simply underestimated the human ability to memorize eight simple S-R mappings. That is, the null effect for the introduction of the transfer items in the S-R condition might have nothing to do with abstract rule knowledge but instead might simply reflect the fact that participants had no problems to learn the new eight S-R mappings at once. Note that this kind of strategy is unlikely to be available for the task-rule condition because task-rule information appears to overrule direct S-R mappings (Dreisbach et al., 2006; Mayr & Bryck, 2005). The purpose of Experiment 2 was to investigate whether the absence of transfer costs in the S-R condition was due to the acquisition of abstract knowledge about S-R features or due to the ability of simply memorizing the eight S-R mappings.

Experiment 2

Experiment 2 was an exact replication of the S-R condition of Experiment 1 with one exception: In the transfer blocks, half of the S-R mappings were task-rule congruent (that is, red color–consonant means right key; red color–vowel means left key as before) the other half of the S-R mappings were task-rule incongruent (that is, red color–consonant means left key; red color–vowel means right key, contrary to training). If participants actually acquire abstract knowledge about stimulus features and response features in the training blocks, we should find increasing

[4] This would also explain the discrepancy to Rogers and Monsell (1995, Experiment 1), who found no effect of transfer items in the task-switching paradigm.

latencies in the transfer blocks but only for task-set incongruent S-R mappings. If, on the other side, participants are simply able to efficiently memorize eight different S-R mappings, we should not find any differences between task-set congruent and incongruent items.

Method

Participants. Twenty five students (14 female, 11 male; mean age = 21.68 years, *SD* = 2.71, range = 19–28) from the Dresden University of Technology, Dresden, Germany, participated for partial course credit or a small financial reward (€2; U.S.$2.55).

Stimuli and procedure. The stimuli and procedure were exactly the same as in Experiment 1 with one exception: Only four of the eight S-R mappings of the transfer items were congruent with the underlying task rules, the other four were incongruent. That is, for the consonant–vowel task, one transfer word starting with a consonant was mapped to the left key (task-set congruent) and one to the right key (hence, task-set incongruent). Accordingly, one transfer word starting with a vowel was mapped to the left key (task-set incongruent), and one was mapped to the right key (task-set congruent). Likewise, for the animal–no animal task, one word depicting an animal was mapped to the left key (congruent) and one to the right key (incongruent) and so on (see Table 1).

Design. An 8 (block) × 2 (task type: repetition, shift) × 2 (task rule congruency: congruent, incongruent) repeated measure design was used. All factors were manipulated within participants. Note that the factor task-rule congruency is realized only in Blocks 7 and 8.

Results and Discussion

Data analytic strategy followed that of Experiment 1. We will first present the results of the overall ANOVA, herein pooling the task-rule congruent and incongruent items of the transfer block. Hereafter, we will present the results of the ANOVA based on the Transfer Blocks 7 and 8 only.

RT data. Figure 4 depicts mean RTs as a function of Block and Task Type. The data resemble those of Experiment 1 in the S-R condition. A 7 (block) × 2 (task type) repeated measures ANOVA yielded a main effect of the factor block, $F(6, 150) = 5.48$, $MSE = 17{,}025.44$. No further effect proved significant (all *p*s > .13, all *F*s < 1.80). In contrast to Experiment 1, the RT increase associated with the transfer items presented in Block 7 only approached significance, $F(1, 25) = 3.59$, $MSE = 3{,}474.99$, $p = .06$.

To find out whether the introduction of task-rule incongruent items incurred a cost, we ran an additional 2 (block: 7 and 8) × 2 (task type) × 2 (task rule congruency) ANOVA with repeated measures. Figure 5 shows the results of this analysis (Block 6 is also included for means of comparison but was not part of the analysis). As can be seen on first glance, task-rule incongruent items are answered slower than task-rule congruent items. Consequently, not only the factor block, $F(1, 25) = 8.81$, $MSE = 3{,}500.49$, but also and of most noted importance the factor task-rule congruency proved highly reliable, $F(1, 25) = 18.88$, $MSE = 3{,}819.13$. Except for the interaction Block × Task Type approaching significance, $F(1, 25) = 2.93$, $MSE = 1{,}488.07$, $p = .09$, no further interaction proved reliable (all *p*s > .2, all *F*s < 1). This supports the assumption that during training participants actually acquired knowledge about stimulus and response features.

Error data. Figure 6 shows mean error rates as a function of block and task type. A 7 (block) × 2 (task type) ANOVA with repeated measures revealed a significant main effect of the factor block, $F(6, 150) = 8.28$, $MSE = 61.69$, reflecting increasing accuracy with increasing practice. As expected, task type was far from significance ($p = .46$, $F < 1$), whereas the interaction Block × Task Type slightly failed to prove reliable, $F(6, 150) = 2.01$, $MSE = 21.42$, $p = .06$. This latter interaction is due to the fact that shifts are more error prone in Block 2, a data pattern that was already observed in Experiment 1. The reason why participants make more errors on task-switch trials as compared with task repetitions is probably due to the fact that in Block 2, 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 by pressing the right key whenever a green stimulus appeared).

To investigate whether participants made more errors on task-set incongruent trials than on congruent trials, a 2 (block: 7 and 8) × 2 (task rule congruency) × 2 (task type) ANOVA with

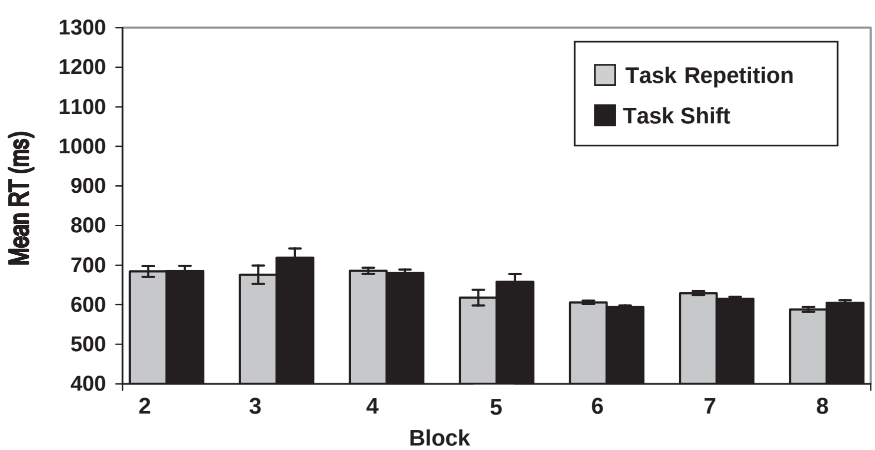

Figure 4. Mean reaction time (RT) as a function of task type and block in the two information conditions in Experiment 2. Error bars represent 95% within-participant confidence intervals based on the corresponding shift–repetition comparison (Loftus & Masson, 1994).

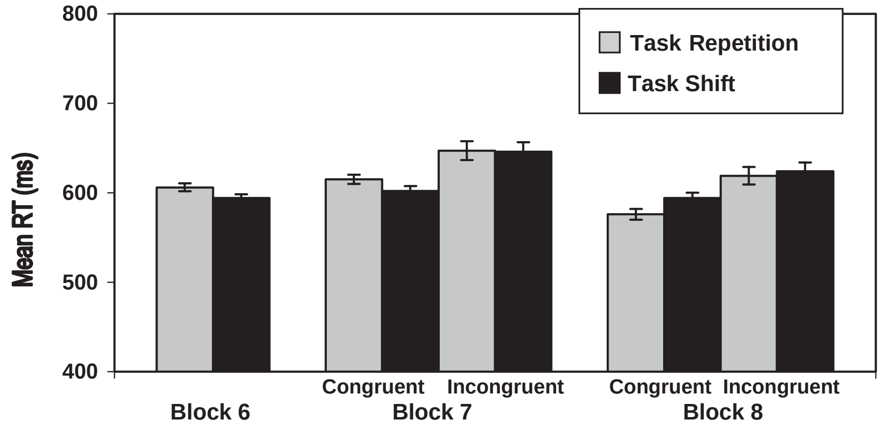

Figure 5. Mean reaction time (RT) as a function of task type and task-rule congruency in Transfer Blocks 7 and 8. Block 6 is presented for comparison reasons only. Error bars represent 95% within-participant confidence intervals based on the corresponding shift–repetition comparison (Loftus & Masson, 1994).

repeated measures was run. No main effect or interaction of this analysis proved reliable (all ps $>$ .20, all Fs $<$ 1.70).

Taken together, the results of Experiment 2 brought up evidence that training participants on single S-R mappings provided, probably as a side effect of task practice, an integration of stimulus and response features. The increased latencies for task-rule incongruent transfer items as compared with task-rule congruent items strongly support the assumption that participants acquired implicit knowledge about the task rules. To rule out that this effect is driven by explicit knowledge about the animal–no animal category, we ran an additional analysis excluding the "incongruent animal." However, the results remained unchanged. Furthermore, in a postexperimental interview none of the participants guessed the underlying task rule. The second surprising result after having found evidence for implicit rule knowledge is that participants still did not produce any switch cost. This suggests that either the application of an implicit task set does not result in switch costs or that participants did not integrate the implicit feature knowledge like "green–animal–left key" and "green–no animal–right key" to one task rule but rather used four different categorization rules to accomplish the tasks. We will come back to this point in the General Discussion.

General Discussion

The experiments presented in this article brought up three main findings. First of all, we replicated previous results by showing again that in this specific design an S-R-based task-processing strategy is more efficient than a task-rule-based strategy (see also Dreisbach et al., 2006). Introducing task-set information at the beginning of the experiment led to significant switch costs from the very beginning and a significant overall cost. Without any task-set information, however, no difference between shifts and repetitions occurred.

Second, we found that the introduction of transfer items increased RTs in the task-rule condition in the first transfer block but did not disrupt task performance in the S-R condition. By contrast, this latter condition had virtually no problems to process eight

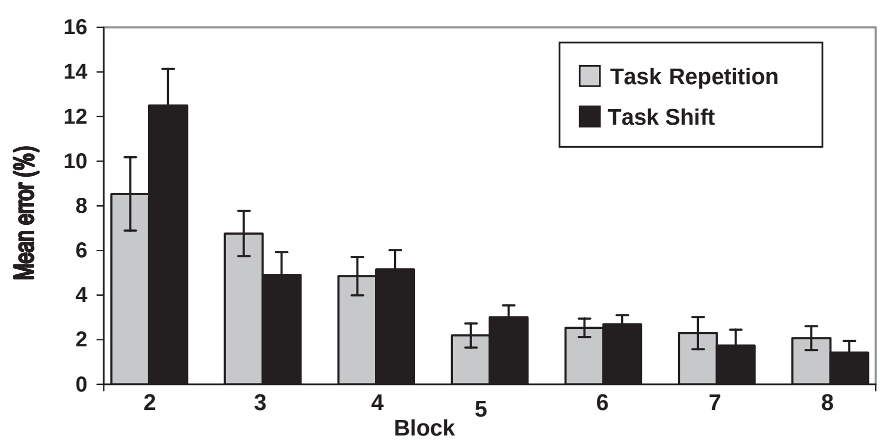

Figure 6. Errors calculated in percentages as a function of task type and block in Experiment 2. Error bars represent 95% within-participant confidence intervals based on the corresponding shift–repetition comparison (Loftus & Masson, 1994).

newly introduced S-R mappings. Along with the significant Task Type × Response Type interaction in the S-R group, we conclude that the irrelevant but salient color feature got integrated into task processing. This observation is in accordance with the literature on response alternation effects showing that even irrelevant stimulus features are integrated into task representation (e.g. Kleinsorge, 1999; Kleinsorge & Heuer, 2000; Notebaert & Soetens, 2003).

Third, we found evidence that participants even acquired knowledge about more subtle stimulus features: Results of Experiment 2 suggest that participants in the S-R condition developed implicit knowledge about the other stimulus features that consistently covaried with the stimulus color and response feature, that is, the first letter of the words and some semantic knowledge. Stimuli in the transfer blocks that were mapped to task-set incongruent response keys were answered significantly slower than task-set congruent stimuli. In post hoc analysis, we made sure that these results cannot be attributed to single stimuli. Even if we entered only half of the stimuli (either only the animal–no animal stimuli or only the consonant–vowel stimuli) into the analysis, the congruency effect remained highly significant.

We thus have shown for the first time that S-R-based processing can turn into rule-based processing if stimulus and response features consistently covary. So what exactly is it that participants have learned in the S-R condition? Did they actually acquire an implicit task set? Note that in Experiments 1 and 2, participants never exhibited any switch costs, even though they produced a significant congruence–incongruence effect in the transfer blocks in Experiment 2. This clearly argues against the assumption that participants used task-set-based information to accomplish the task (unless one holds that the application of implicit task sets, as compared with explicit task sets, do not result in cost). Furthermore, from our previous work we know that switch costs occur as soon as participants know about the task rules even after they had already successfully learned and applied the S-R mappings (Dreisbach et al., 2006).[5] We therefore assume that participants in the S-R condition presumably learned to integrate abstract stimulus and response features to categorization rules. That is, we assume that participants (implicitly) learned to associate red with consonant and green with animal for the left response key and red with vowel and green with no animal with the right response key. To make clearer how this association between stimulus features, color, and response might work, take the following example: A word that does not represent an animal is only task-rule incongruent if it is mapped to the left response and written in green. The very same word written in red would not (necessarily, depending on the first letter) be task-rule incongruent. The same holds for the letter task: Whether a word is task-rule congruent clearly depends on the first letter and on the color of the word.[6]

However, obviously participants did not integrate these four categorization rules into two task rules. Thus, participants did not switch between two task sets (and consequently did not produce switch costs) but rather between four different categorization rules. This would also explain the data pattern of the Task Type × Response Type interaction in the S-R condition that differs significantly from the corresponding interaction in the task-rule condition: A closer look at Figure 3 reveals that the Task × Response interaction in the S-R condition is mainly due to a response repetition benefit for task repetitions and is not, as commonly found and evident in the task-rule condition, due to response repetition costs for task shifts (e.g. Notebaert & Soetens, 2003). However, this data pattern completely makes sense if one assumes that participants in the S-R condition switched between four different categorization rules. In this case, a task (or better color) repetition along with a response repetition represents the only *pure* task repetition, that is, the repetition of a categorization rule.[7] Any other combination, be it a task repetition with a response switch or a task switch with response repetition or response switch represents a switch of the categorization rule and consequently results in slower RTs.

In summary, the observed null effect in the transfer blocks along with the response alternation effects in Experiment 1 and the incongruence effects in Experiment 2 support the assumption that S-R-based processing can turn into rule-based processing. Thus, whereas Logan and colleagues (Logan & Bundesen, 2003; Schneider & Logan, 2005) could show that participants can adopt a compound-stimulus strategy when switching between simple cognitive tasks that follows the underlying task rules thereby leading to (cue) switch costs, we could show that participants starting with an S-R-based strategy rather use categorization rules but presumably do not integrate these categorization rules into the superordinate task rules.

Do our results help to shed some light into the controversial debate on hidden covaration learning (e.g., Hendrickx et al., 1997; Lewicki et al., 1994)? On first glance, the results fit nicely with the assumption that hidden covariation learning is possible even within these simple S-R mapping tasks. However, we are agnostic with respect to questions of consciousness and awareness that were not in the focus of this research. Even though we asked participants after the experiment what kind of strategy they had used to memorize the S-R mappings (and no participant reported any specific knowledge), we cannot exclude that participants have acquired some explicit knowledge about the underlying task rules. In addition, even though in our opinion awareness about the underlying task rules is highly unlikely because otherwise switch costs should have occurred, more research is clearly needed to show that the presence or absence of switch costs can actually be

[5] We also ran this S-R–task-rule condition in Experiment 1 in which participants started with the S-R mappings and then after Block 4 were casually informed about the two underlying task rules. Like in our previous work (Dreisbach et al., 2006), participants produced switch costs right after the introduction of the task rules showing that as soon as task rules are available, participants cannot refrain from using them. Results are not presented here but can be reported on request.

[6] An alternative experimental approach to support this assumption would have been to simply reverse the mapping of color and rule in the transfer blocks of Experiment 1. That is, words that (implicitly) follow the consonant–vowel rule would now be written in green and words that follow the animal–no animal rule would now be written in red. According to our assumption, in this kind of design (and using the same transfer stimuli as in Experiment 1), any green word mapped to the left key would be task-rule incongruent and thus answered slower, any green word mapped to the right key would be task-rule congruent. As for the red words, task-rule congruency would depend on the first letter of a given stimulus, that is, one task-rule congruent and incongruent would be mapped to the left and the right response key.

[7] Note that this effect cannot be explained by exact stimulus repetitions because they were excluded from the analysis.

taken as a diagnostic for the conscious awareness in such a task setting. So, in this respect our data are not suited as a proof for unconscious covariation learning. Also with respect to a second highly debated issue, namely the amount of attention that is needed to find effects of implicit learning (e.g., Jiménez & Mendez, 1999), our results give no clear answer because we cannot know how much attention was involved in the processing of single stimulus features. Future research will have to address this issue. For example, implementing the paradigm used in Experiment 2 in a dual task environment would help to understand how much attention is needed for implicit rule acquisition.

The general conclusion from the current findings so far is that S-R-based task processing can turn into rule-based processing. This rule-based processing, however, does not result in switch costs. Remember that Logan et al. (Logan & Bundesen, 2003; Schneider & Logan, 2005) have shown that rule-based processing can turn into S-R-based processing and still result in switch costs. That is, the presence of switch costs does not necessarily imply the involvement of task rules (Logan & Bundesen, 2003; Schneider & Logan, 2005), but neither does the absence of switch costs imply that no rule-based knowledge was involved. This should be kept in mind whenever switch costs are interpreted.

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