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Task-Switching Costs Disappear if Non-Chinese Participants Respond to Chinese Characters

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In experiments with univalent target stimuli, task-switching costs can be eliminated if participants are unaware of the task rules and apply cue-target-response associations. However, in experiments with bivalent target stimuli, participants show task-switching costs. Participants may exhibit switch costs even when no task rules are provided in the instructions because they can infer the task rules. We tested this prediction by controlling the meaningfulness of cues and targets and therefore the ability to apply the task rules in 2 groups of participants. We compared the performance of Chinese and non-Chinese participants, who responded to Chinese numerals in an odd/even and high/low number task. In Experiment 1, Chinese participants, who knew Chinese characters and understood the task rules, showed task-switching costs. Non-Chinese participants on the other hand, who did not know Chinese characters, exhibited no switch costs. They applied a "target-first" strategy which means that they processed the target stimulus before the cue. In Experiment 2, we confirmed the absence of task-switching costs in Chinese participants using traditional Chinese numerals as target stimuli. Further, to determine how the target-first strategy affects switch costs, we manipulated the sequence of cue and target presentations. We conclude that task-switching costs can be eliminated more easily than previously thought, even for bivalent stimuli. The occurrence of task-switching costs depends on the approach used by participants and this may answer the puzzling question why humans typically do show task-switching costs whereas pigeons and monkeys do not.

Keywords: task-switching, bivalent stimuli, stimulus-response association, task-switching cost

It is well established that switching between tasks from one trial to the next leads to slower responses and more errors, also known as "task-switching costs" (Grange & Houghton, 2014; Jersild, 1927; Koch, Poljac, Müller, & Kiesel, 2018; Vandierendonck, Liefooghe, & Verbruggen, 2010). Previous studies have assumed that switch costs can only occur when participants have established mental representations of two or more underlying task sets (cf. Vandierendonck et al., 2010). More recently, Forrest (2012) and Forrest, Monsell, and McLaren (2014) have challenged this assumption. They reported that participants showed significant task-switching costs even when they were unaware of the task rules and appeared to respond by using cue-target-response (CTR) associations, similar to a list in a lookup table. In the following we studied whether participants who cannot apply the task-switching rules nevertheless show switching costs, and whether they exclusively use CTR associations in a standard task-switching paradigm.

Cue-Target-Response Associations

Task cueing is one of the most popular task-switching paradigms (Meiran, 2014). In each trial, a task cue is presented that indicates which task a participant has to perform on a subsequently presented target stimulus. In a typical task-cueing paradigm there are only two tasks to perform and the participant switches between them in a randomized sequence of trials. In order to respond correctly, the participant needs to apply the relevant task rule when the target stimulus appears. A task-cueing experiment has usually a small number of target stimuli that appear repeatedly throughout the experiment (e.g., Dreisbach, Goschke, & Haider, 2006, 2007; Dreisbach & Haider, 2008; Forrest, 2012; Forrest, Monsell, & McLaren, 2014; Logan & Bundesen, 2003). Therefore, it is unclear whether participants do always apply the task rules or simply recall CTR associations.

In a series of studies, Dreisbach, Goschke, and Haider (2006, 2007) and Dreisbach and Haider (2008) instructed participants to use CTR associations without explaining the task-switching rules. They found that CTR associations eliminated task-switching costs for univalent target stimuli where each target stimulus is associated with a single task and response. In contrast, bivalent target stimuli

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always have two sets of features, where each set is associated with a single task. Surprisingly, participants who were instructed to use CTR associations, called cue-stimulus response (CSR) associations by Forrest (2012) and Forrest et al. (2014), exhibited significant residual task-switching costs in task-switching studies with bivalent target stimuli. Although Forrest (2012) and Forrest et al. (2014) observed that participants who received CTR instructions had smaller switch costs than participants who received conventional rule-based instructions, their switch costs were still significantly larger than zero.

Associative Learning Account of Task-Switching Costs

Bivalent target stimuli contain information that is relevant to both tasks because both tasks share the same stimulus-set. For example, in the odd-even/low-high number discrimination task by Forrest et al. (2014) the *left key* is associated with an odd and a lower-than-five number, and the *right key* is associated with an even and a higher-than-five number. The digit "3" and "6" are congruent stimuli because they require pressing the same response key in the odd-even and low-high task. In contrast, the digits "2" and "9" are incongruent stimuli because they require pressing different response keys in both tasks. In the context of task-switching, participants usually respond faster to congruent stimuli than to incongruent stimuli. This well-established effect on response times (RTs) and error rates (ERs) is known as the "congruency effect" (e.g., Kiesel, Wendt, & Peters, 2007; Meiran & Kessler, 2008; Reisenauer & Dreisbach, 2014; Schneider, 2015; Schneider & Logan, 2015).

If participants employ CTR associations in a task-cueing paradigm with bivalent target stimuli, then task-switching costs may occur due to associative learning in incongruent trials (Forrest, 2012; Forrest et al., 2014). Bivalent stimuli in incongruent trials give rise to different associative structures than bivalent stimuli in congruent trials. Bivalent stimuli in congruent trials can be learned from a single target feature (e.g., Cue A + Stimulus X ⇒ *left*; Cue B + Stimulus X ⇒ *left*; the cue is redundant). In contrast, incongruent trials require "biconditional discrimination" learning (e.g., Cue A + Stimulus X ⇒ *left*; Cue B + Stimulus X ⇒ *right;* the correct response needs to be inferred by both task cue and target stimulus). Compared with congruent trials, the associative structure in incongruent trials is harder to learn for human participants (Harris & Livesey, 2008; Livesey, Thorwart, De Fina, & Harris, 2011).

Forrest (2012) and Forrest et al. (2014) proposed that due to "biconditional discrimination" learning in task-switching, associative learning can generate small but reliable task-switching costs. This form of associative learning requires no explicit representation of the underlying task rules or task sets.

To demonstrate this, Forrest et al. (2014) modeled their data using the Adaptively Parameterized Error Correcting System (APECS), a backpropagation connectionist network with three layers (McLaren, Forrest, & Mclaren, 2012). Trial by trial, the APECS model learned the correct response for a given cue and target combination by adjusting weights between input units, hidden units, and output units, without a control mechanism. Forrest et al. (2014) conducted 32 computer simulations. In each simulation they assigned a new random set of initial weights and treated the results of each simulation as observations from a pseudoparticipant. The results suggest that the APECS model performed significantly worse in "switch trials" than "repeat trials," suggesting that an unsupervised associative learning network can produce task-switching costs without applying task rules or other control mechanisms.

However, studying associative learning empirically rather than computationally has a major drawback. In a number of studies on associative learning, participants performed in task-switching experiments without receiving explicit instructions about the task rules. As a consequence, the researchers *assumed* that participants could not infer and apply task rules and that participants used CTR associations instead. It is difficult to verify whether a participant applied the task rules or not and researchers typically rely on verbal self-reports of each participant after an experiment. Forrest (2012) and Forrest et al. (2014), for example, replaced participants who reported that they had applied the task rules in their experiment. According to their records at least 11 out of 43 participants, who were instructed to use CTR associations, were able to learn and infer the task rules.

In addition, Meier, Lea, Forrest, Angerer, and McLaren (2013) and Meier, Lea, and McLaren (2016) argued that some participants, who did not verbalize the task rules explicitly, might have used the task rules implicitly. This would explain why task-switching costs were reduced but still significant in a group of participants that were instructed to use CTR associations. As argued by Meier et al. (2013, 2016), it is difficult to control task-switching strategies of human participants. In order to demonstrate that CTR associations can eliminate task-switching costs, they conducted a study with task-cueing in pigeons. They reasoned that pigeons do not have high-level cognition and executive control (but see Castro & Wasserman, 2016; Soto & Wasserman, 2010) and therefore can only perform task-switching through associative learning. Indeed, pigeons showed no task-switching costs, even when the target stimuli were bivalent (Meier, Lea, Forrest, Angerer, & McLaren, 2013; Meier, Lea, & McLaren, 2016). Interestingly, monkeys do not show switch costs either, despite evidence that they use and represent task rules (Stoet & Snyder, 2003, 2004, 2007, 2009; Avdagic, Jensen, Altschul, & Terrace, 2014). The latter suggests that eliminating switch costs may be possible without having to rely on CTR associations. The question then is how this can be achieved in a standard experimental task-switching paradigm.

Aims of the Current Study

Here we sought to examine and elaborate on an alternative explanation of Forrest (2012) and Forrest et al.'s (2014) results that was put forward by Meier et al. (2013, 2016). Meier and colleagues claimed that task-switching costs with bivalent target stimuli are the result of insufficient control of the use of task rules in human participants. If this explanation is correct, then task-switching costs should disappear if participants cannot apply task rules in a task-cueing paradigm with bivalent target stimuli. In other words, we sought to confirm the absence of task-switching costs in human participants who remain completely ignorant about the semantic meaning of cues, target stimuli and therefore the task rules.

We therefore invited Chinese and non-Chinese participants and asked them to respond to numbers as target stimuli that were presented as simplified Chinese characters in Experiment 1 or as traditional Chinese characters in Experiment 2. Simplified Chinese characters are commonly used whereas traditional Chinese characters are rarely used in everyday settings of Chinese communities. In the following, we distinguish between "non-Chinese participants" (those who cannot read or speak Chinese at all) and "Chinese participants" (those who can read and speak Chinese fluently). We exploited this "language barrier" between the two groups of participants in order to investigate systematic differences in task-switching performance with and without prior knowledge of cues and target stimuli and therefore the ability to infer the task rules.

Experiment 1

In this cued task-switching experiment, we employed the standard parity (odd/even) task and a magnitude (high/low) task. We used two task cues and four (single-digit) numbers as target stimuli. In contrast to previous studies, we presented the task cues and numbers as simplified Chinese characters so that only participants who knew and understood these characters would be able to apply the task rules. Importantly, the same task cues and target stimuli were used by the non-Chinese participants. For participants who do not understand Chinese these characters should have no semantic meaning. Consequently, it was impossible for non-Chinese participants to identify the *task-relevant* features of the target stimuli, that is, magnitude or parity of a number. We hypothesized that these participants have to rely on CTR associations and should therefore develop no task-switching costs in terms of response times (RTs) and error rates (ERs). In contrast, the associative learning account of task-switching postulates that non-Chinese participants should also show task-switching costs (Forrest, 2012; Forrest et al., 2014). This is because an unsupervised associative learning network can produce task-switching costs without applying task rules or other control mechanisms (Forrest et al., 2014).

In Experiment 1 we also investigated ~~reaction time (~~RT~~)~~ and ER congruency effects in task-switching. Previous studies have suggested that in the absence of task rules participants show significant congruency effects. Participants also reacted more slowly and made more mistakes in incongruent trials than in congruent trials (Forrest, 2012; Forrest et al., 2014). Thus, the second aim of Experiment 1 was to establish whether or not participants, who do not understand the meaning of the stimuli and therefore cannot apply task-switching rules, would exhibit congruency effects.

Method

We investigated task-switching effects in a three-way ANOVA with repeated measurements and within-between interactions. A statistical power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) indicated an optimal sample size of $N = 46$ for medium effect size $f = 0.25$, $\alpha = .05$, and power = 0.9 with 23 participants in each group.

Participants. A total of 32 non-Chinese and 24 Chinese students ($N = 56$, female = 40; mean age = 22.6, $SD = 3.35$) from the University of Glasgow took part in Experiment 1. We established balanced samples of 24 Chinese and 24 non-Chinese participants because eight students from the 32 non-Chinese students did not achieve a sufficiently low error rate in incongruent trials and had to be removed. Each participant received £3 for taking part and were naive as to the tasks and purpose of the experiment. The Chinese students were international students from mainland China whereas the non-Chinese students came from different Western countries and reported to have no knowledge of Chinese characters.

Research ethics. Research was in accordance with the declaration of Helsinki, and approval of ethical standards for Experiments 1, 2A, and 2B was given by the Glasgow University College of Science and Engineering ethics committee. All participants gave written and verbal consent to participate.

Apparatus and stimuli. The experiment was programmed using PsyToolkit (Stoet, 2010, 2017). All stimuli were presented at the center of a 24-in. computer screen. A Black Box Toolkit response box was used to record participants' responses (correct and incorrect) and RTs with ±1-ms precision. Participants used a QWERTY keyboard to go through instructions and to start the experiment. The four target stimuli were the single-digit numbers 4, 5, 6, and 7 displayed as *simplified Chinese* characters 四,五,六 and 七, respectively. The two task cues were also simplified Chinese characters: 质 (quality) served as the cue for the odd/even task; 量 (quantity) served as the cue for the high/low task. The size of each Chinese character was 17 mm × 17 mm. All stimuli were displayed in green (RGB: 0, 255, 0) on a black background (RGB: 0, 0, 0) to avoid eye strain.

Procedure. The participants were seated in front of the computer screen with a viewing distance of 40–60 cm. The non-Chinese participants received instructions that were not based on the task rules. These instructions listed all combinations between cue-stimulus and response keys, and required participants to memorize them. The Chinese participants received instructions based on the task rules. These instructions explained that for the parity task, participants had to decide whether a number was odd or even (odd ⇒ press the *left* key; even ⇒ press the *right* key). For the magnitude task, participants had to decide whether a number was low (4 or 5, press the left key) or high (6 or 7, press the right key). The experiment consisted of one block of 20 training trials followed by four blocks of 75 experimental trials resulting in a total of 300 experimental trials.

Experiment 1 used a composite design. In each trial, a task cue and target stimulus appeared simultaneously on screen. The target number was presented underneath the task cue (Figure 1a) and stayed on screen until a response was made or a maximum of 2,500 ms was exceeded. If the participants failed to respond within 2,500 ms, a "time out" message (written in English for all participants) appeared for 3 s. If the participants made a mistake, the message "mistake" (written in English for all participants) appeared for 3 s. The intertrial interval (ITI) was always 300 ms. After the experiment, each participant was asked to report the strategy they had applied during the experiment. F1

Analyses. The data were analyzed with the statistical software R Version 3.4.2 (R Core Team, 2017). In the following analyses, all training trials and trials following incorrect trials were excluded. If participants made a mistake in *trial* $n - 1$, *trial n* cannot be categorized as a switch trial or repeat trial. Moreover, if *trial* $n - 1$ and *trial n* had the same cue-target combination, *trial n* was removed because participants could simply repeat the response

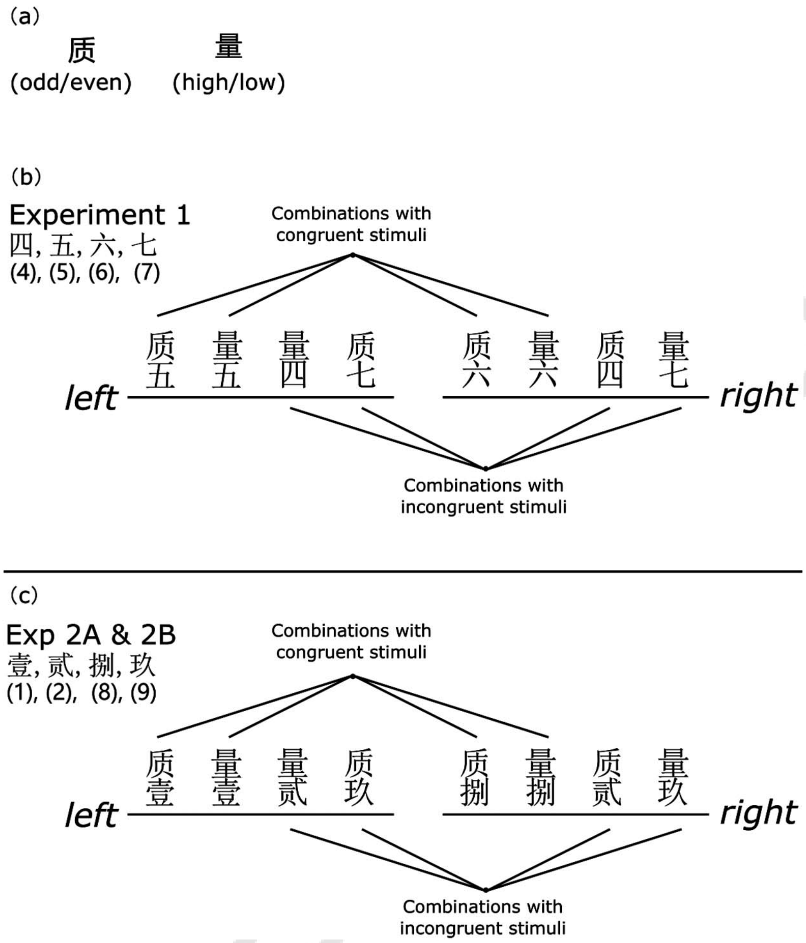

Figure 1. Illustration of the Chinese characters used as task cues and target stimuli and their combinations. (a) Cues for odd/even and high/low task. (b) Simplified Chinese numbers as stimuli and all eight cue-stimulus combinations and key presses (*left*, *right*) for correct responses in Experiment 1. The character on the top of each combination is the task cue, and the character on the bottom is the target stimulus (number). (c) Traditional Chinese numbers as target stimuli and all cue-stimulus combinations and key presses (*left* or *right*) for correct responses in Experiments 2A and 2B. Note that the simplified and traditional Chinese numerals look very different.

from trial $n - 1$ without any cognitive effort. All error trials were excluded from the RT analysis.

Results

We excluded participants whose error rates were not significantly different from chance. Eight non-Chinese participants with mean error rates ranging from 31% to 60% in incongruent trials (binomial test with $p < .05$) had to be replaced to achieve balanced samples of 24 Chinese and 24 non-Chinese participants. Each of the remaining participants had an overall ER of less than 20%. A more rigorous exclusion criterion might have obscured the difference in ERs between Chinese and non-Chinese participants. Mean RTs, ERs, and corresponding SEMs and *SD*s for each trial condition and language group are shown in Figure 2 and are listed in the ~~Appendixes~~, respectively. F2

Analysis of RTs. A three-way ANOVA was conducted to compare the mean RTs between and within conditions. The two within-subjects factors were trial transition (switch, repeat) and congruency (congruent, incongruent). The between-subjects factor was language group (Chinese, non-Chinese). The results of this analysis are summarized in Table 1 and illustrated in Figure 2. T1

The three statistically significant main effects were moderated by two-way interactions (see Figure 2): The interaction between trial transition and language group was statistically significant. In the following, post hoc pairwise comparisons were always adjusted for multiple comparisons after Holm (1979). Pairwise comparisons revealed that trial transition had a statistically significant effect in the Chinese group (switch − repeat = +99 ms, $p < .001$, $d = .65$) but not in the non-Chinese group (switch − repeat = −9 ms, $p = .48$, $d = -.06$).

The interaction between congruency and language group was also statistically significant. Pairwise comparisons showed that the effect of congruency was statistically significant for the non-Chinese par-

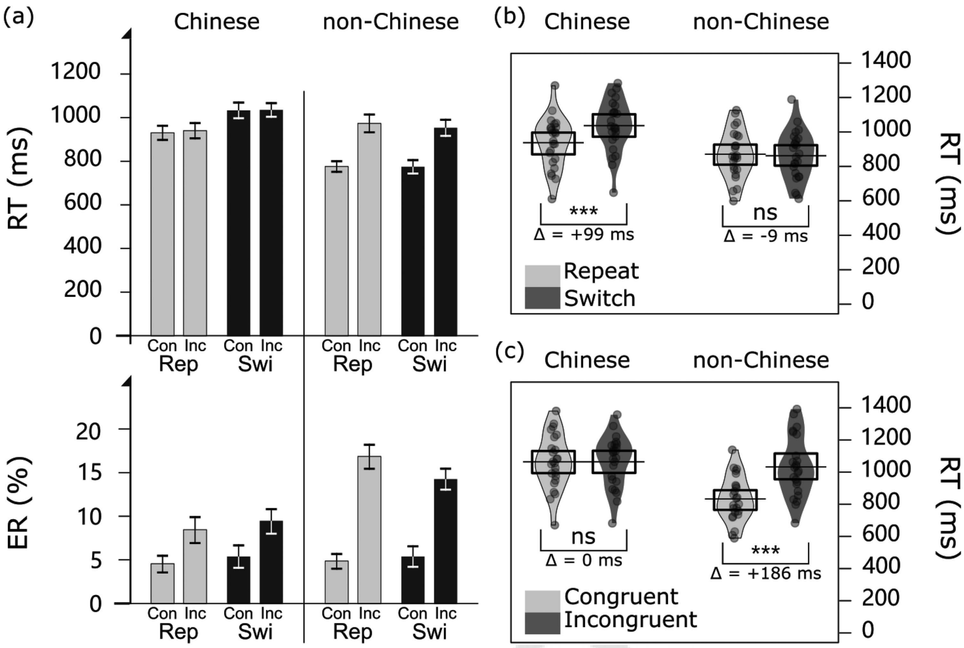

Figure 2. Results of Experiment 1. (a) The bar graph on top displays RTs and the bar graph below displays ERs of each trial condition (repeat congruent, repeat incongruent, switch congruent and switch incongruent). The error bars denote ±1 SEM. (b) The violin plots illustrate RT distributions for the repeat and the switch condition in each language group (Chinese, non-Chinese). Jittered dots inside the violin plots represent average RTs for each participant. The black horizontal bar and the box around it represent the mean and 50% CI of the mean in each condition, respectively. (c) Violin plots illustrate RT distributions for the congruent and incongruent condition in each language group. Con = congruent; Inc = incongruent; Rep = repeat; Swi = switch. *** $p <$ .001. ** $p <$ .01. * $p <$ .05. *ns* = nonsignificant.

ticipants (incongruent − congruent = +186 ms, $p < .001$, $d = 1.06$) but not for the Chinese participants (incongruent − congruent = 0 ms, $p = .99$, $d < .001$). In addition, the difference in RT between the two language groups was only significant in the congruent condition (Chinese congruent − non-Chinese congruent = 216 ms, $p < .001$, $d = 1.65$) but not in the incongruent condition (Chinese incongruent − non-Chinese incongruent = 30 ms, $p = .52$, $d = .17$).

Analysis of ERs. An equivalent three-way ANOVA with mixed effects was conducted on mean ERs. The results of this analysis are summarized in Table 1 and illustrated in Figure 2. There was a statistically significant interaction between congruency and language group. Post hoc pairwise comparisons revealed that the congruency effect was statistically significant in both language groups (Chinese: incongruent − congruent = +3.93%, $p < .001$, $d = .71$; non-Chinese: incongruent − congruent = +10.25%, $p < .001$, $d = 2.38$). However, the congruency effect was significantly larger for non-Chinese participants than Chinese participants: 10.25% versus 3.93%.

Table 1
Experiment 1: Results of Two Mixed Effect ANOVA on RT and ER, Using Trial Transition (Repeat, Switch) and Congruency (Congruent, Incongruent) as Within-Subjects Factors, and Language Group (Chinese, Non-Chinese) as Between-Subject Factor

	RT				ER			
Factor	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
L	7.99	1, 46	.007	.148	8.48	1, 46	.006	.156
T	23.14	1, 46	<.001	.335	.001	1, 46	.967	<.001
C	32.54	1, 46	<.001	.414	89.74	1, 46	<.001	.661
L × T	33.54	1, 46	<.001	.427	3.06	1, 46	.089	.062
L × C	28.71	1, 46	<.001	.384	17.86	1, 46	<.001	.278
T × C	1.11	1, 46	.297	.024	1.40	1, 46	.242	.030
L × T × C	.19	1, 46	.663	.004	1.80	1, 46	.186	.037

Note. L = language; T = trial transition; C = congruency.

Practice effect. With two additional four-way ANOVAs we investigated RT and ER switching costs in the first and second half of the experiment for each language group. Mean RTs, ERs, and corresponding *SD*s are listed in the ~~Appendixes~~. The three within-subjects factors were trial transition (switch, repeat), congruency (congruent, incongruent), and sequence (first half, second half). The between-subjects factor was language group (Chinese, non-Chinese). The main effect of sequence on RT was significant, $F(1, 46) = 26.18$, $p < .001$, $\eta_p^2 = .363$, and for ER, $F(1, 46) = 31.94$, $p < .001$, $\eta_p^2 = .409$. Participants had shorter RTs in the second half of the experiment (Block 3–4; 893 ms) than in the first half of the experiment (Block 1–2; 970 ms), and they had lower ERs in the second half of the experiment (6.73%) than in the first half of the experiment (10.87%).

For RTs and ERs, sequence did not significantly interact with any of the other factors. However, for RTs, the interaction between trial transition and sequence approached significance, $F(1, 46) = 3.95$, $p = .053$. Chinese participants had a smaller trial transition effect in the second half than in the first half. Pairwise comparisons suggested that the effect of trial transition was significant in both the first (switch − repeat = +115 ms; $p < .001$, $d = .67$) and the second half (switch − repeat = +85 ms; $p < .001$, $d = .61$) of the experiment. For non-Chinese participants, the effect of trial transition was not significant in either the first (switch − repeat = +2 ms, $p > .05$) and the second half (switch − repeat = −21 ms, $p > .05$).

No switching costs. In Experiment 1 we were not only interested in the difference in switching costs between Chinese and non-Chinese participants but also whether non-Chinese participants would show switching costs at all. In a conventional frequentist approach we can only test against the null-hypothesis (Jarosz & Wiley, 2014). Therefore, we computed a Bayes factor (Morey & Rouder, 2011) to establish the odds between the null hypothesis (H_0) that non-Chinese participants had no switch costs and the alternative hypothesis (H_1) that non-Chinese participants had switch costs. The corresponding Bayes factor (BF = 3.72) indicates that the data were almost four times more likely to be observed under H_0 than under H_1.

Self-reports. All Chinese participants reported that they had applied the task rules in the experiment. In contrast, all non-Chinese participants reported that they had *not* simply applied CTR associations but a mixture of rule-based and CTR associations which we labeled "target-first" strategy. According to this strategy non-Chinese participants first looked at the target stimuli or Chinese numeral at the bottom of the composite cue-stimulus. If the bottom character was 五 (5), they pressed the *left* key. If it was 六 (6), they pressed the *right* key. The task cue appearing on top was irrelevant for 五 and 六 because these two characters were congruent target stimuli sharing the same response key in both tasks. However, if the bottom character was 四 (4) or 七 (7), the correct answer was determined in combination with the character displayed on top:

四: IF 量 THEN *left*; IF 质 THEN *right*

七: IF 量 THEN *right*; IF 质 THEN *left*

The observation that participants might use this target-first strategy, a mixture of rules and associations, has been noted before (Forrest, 2012; Forrest et al., 2014) but possible implications for task-switching were not discussed.

Discussion

In line with our hypothesis, task-switching costs were only observed in the group of participants who knew and understood Chinese characters. Task-switching costs were not significant for non-Chinese participants and the Bayes factor provided moderate evidence (Jeffreys, 1961) in favor of the null hypothesis that non-Chinese participants had no task-switching costs.

All non-Chinese participants reported that they applied a mixed strategy rather than CTR associations as instructed. In task-switching and other cognitive tasks, participants may try to reduce uncertainty (Cooper, Garrett, Rennie, & Karayanidis, 2015; Mackie, van Dam, & Fan, 2013) and simplify decisions (Gigerenzer, Todd, & the ABC Research Group, 1999; Newell & Simon, 1972). When no rule-based instructions were given, participants developed a new target-first strategy that seemed to prioritize goal-relevant information. Forrest and colleagues noticed the same strategy (Forrest, 2012; Forrest et al., 2014) but argued that participants' self-reports were not reliable and that a verbal report after the experiment did not necessarily reflect the strategy that was employed during the experiment. The non-Chinese participants showed significant congruency effects in terms of shorter RTs and lower ERs in congruent trials. In previous studies significant RT congruency effects were reported even when participants did not appear to apply the task rules (Forrest, 2012; Forrest et al., 2014). In contrast, the Chinese participants in our experiment had no significant RT congruency effect although the ER congruency effect was significant. Apparently, Chinese participants had an advantage in congruent trials in terms of ER but not RT. Compared with the non-Chinese participants, the Chinese participants had longer RTs in congruent trials. However, both Chinese and non-Chinese participants had similar RTs in incongruent trials. This pattern of results suggest a dissociation between trial transition and congruency effect between the two language groups and therefore between task rules and target-first strategy. Applying the task rules reduced RTs in trials with task repetition whereas the target-first strategy helped to shorten RTs in congruent trials. However, it is unclear whether the absence of an RT congruency effect in Chinese participants was the result of the Chinese numerals as target stimuli, the application of the task rules or both. In the following control experiments, we presented the task cue and target stimulus in different orders to manipulate the use of the task rules and the target-first strategy. This manipulation allowed us to monitor task-switching costs and congruency effects across conditions.

Because all Chinese participants in Experiment 1 applied the task rules, we cannot directly compare our results with the results on CTR association (Forrest, 2012; Forrest et al., 2014). In those studies, task-switching costs remained significant although participants reported that they had no understanding of the task rules. In Experiment 2A, we addressed this issue by instructing Chinese participants to use CTR associations rather than task rules. In addition, in Experiments 2A and 2B, we sought to further investigate the target-first strategy in terms of RTs and ERs. In short, we predicted that participants who use the target-first strategy would engage in a "target-based" rather than a more conventional "cue-based" preparation process.

In two additional analyses we investigated practice effects, because all participants had shorter RTs and lower ERs in the second half of the experiment (Block 3–4) than in the first half of the experiment (Block 1–2). However, this practice effect did not interact with task-switching costs. Non-Chinese participants showed no task-switching costs in either the first or second half of the experiment, and Chinese participants consistently showed switch costs throughout the experiment.

Experiment 2A

The main aim of Experiment 2A was to replicate the results of Experiment 1 with traditional Chinese numbers as targets and new samples of Chinese and non-Chinese participants but without instructing the task rules. We expected that Chinese participants would show significant task-switching costs as in Experiment 1 because they can infer the task rules. However, they may not be able to verbalize the task rules since traditional Chinese numbers are rarely used for arithmetic operations. We further predicted that non-Chinese participants cannot infer the task rules and therefore should not show task-switching costs, replicating the results of Experiment 1. In contrast, associative learning models suggest that participants should generate task-switching costs even when they cannot verbalize the task rules (Forrest, 2012; Forrest et al., 2014). Thus, regardless of their awareness of the task rules, both Chinese and non-Chinese participants should exhibit task-switching costs.

In Experiment 1, all non-Chinese participants reported that they applied the target-first strategy but previous studies have suggested that self-reports after an experiment may be unreliable (Forrest et al., 2014). As a consequence, we sought evidence for the use of the target-first strategy in Experiment 2A by varying the presentation order of cue and target in a cue-first and target-first condition. In an additional control and similar to Experiment 1, we also displayed cue and target together in a composite condition.

Typical task-cueing trials include a cue-target interval where a task cue appears before a target. This allows participants to engage in "cue-based" preparations: By preparing a task-specific response in advance of the target stimulus overall RTs and switch costs are reduced (e.g., Forrest et al., 2014; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Schneider, 2016, 2017; Verbruggen, Liefooghe, Vandierendonck, & Demanet, 2007).

In previous studies, a variant of the task-cueing paradigm has been used, in which the sequence of the task cue and target presentation was reversed (e.g., Ruge, Braver, & Meiran, 2009; Schneider & Logan, 2014a). That is, in the target-first condition the target appeared first, followed by the "task cue" after a short delay. We predicted that participants, who apply the target-first strategy, process the target before the cue appears and therefore should be able to utilize the interval between target and cue to enhance their performance in the target-first condition. In contrast, we predicted that participants, who apply the task rules, process the cue before the target and therefore would not be able to utilize the target-cue interval in the target-first condition, leading to larger RTs and ERs.

In short, the two main predictions for Experiment 2A were: (a) Only Chinese participants may show significant task-switching costs due to the use of implicit task rules. Unsupervised associative learning, however, predicts significant task-switching costs in both language groups. (b) Participants, who apply the target-first strategy, should show no task-switching costs but a strong congruency effect. Furthermore, they should show reduced RTs and ERs in the target-first compared to the cue-first condition. If, however, participants apply the task rules, the reversed pattern with increased RTs and ERs in the target-first compared to the cue-first condition should occur.

Method

We planned to test task-switching effects in a four-way ANOVA with repeated measurements and within-between interactions. A statistical power analysis (Faul et al., 2007) indicated an optimal sample size of $N = 36$ for a medium effect size $f = 0.25$, $\alpha = .05$, and power = 0.9 with 18 participants in each group.

Participants. A total of 32 non-Chinese and 18 Chinese students from the University of Glasgow took part in Experiment 2A ($N = 50$, female = 32; mean age = 22, $SD = 2.40$). The 18 Chinese students were international students from mainland China whereas the 32 non-Chinese students came from European countries. Each participant received £4 for taking part and were naive as to the tasks and purpose of the experiment. Due to the difficulty of the task, especially for non-Chinese participants, 16 non-Chinese and two Chinese participants did not perform better than chance in the incongruent trials of one of the stimulus order conditions and had to be excluded.

Apparatus and stimuli. The equipment was the same as in Experiment 1. The two task cues were identical to Experiment 1, but we introduced traditional Chinese numerals as target stimuli. In Experiment 1, the target numerals, written in simplified Chinese, corresponded to the numbers 4, 5, 6, and 7. In Experiment 2, we used the numbers 1, 2, 8, and 9 in order to accentuate the low/high number task. However, simplified Chinese numerals 一 (1), 二 (2), and 八 (8), 九 (9) are not ideal for this task because low numerals 一 (1) and 二 (2) have horizontal features, whereas high numerals 八 (8) and 九 (9) have mainly vertical features. Therefore, non-Chinese participants may simply apply the "horizontal/vertical" features as task rules: IF horizontal THEN left; IF vertical THEN right. The use of these features would be essentially equivalent to the low/high task rule. In order to rule out the use of "horizontal/vertical" features, we employed traditional Chinese numerals 壹 (1), 贰 (2), and 捌 (8), 玖 (9) as target stimuli.

Procedure. The participants were seated in front of the computer screen with a viewing distance of 40–60 cm. All participants received instructions that did not state the task rules but instead listed all combinations between cue-stimulus and response keys. Participants were asked to memorize them. The response mappings are listed in Figure 1c.

This experiment had two parts. All participants completed the composite condition in the first part. In the second part the cue-first and target-first condition was counterbalanced across participants. In the composite condition, the task cue and the target stimulus appeared simultaneously on screen. A traditional Chinese number was presented at the bottom, and the Chinese task cue was presented at the top. As soon as the target stimulus appeared on screen the participant had to respond within 2,500 ms or a timeout would occur. The task cue and target stimulus would stay on screen until the maximum RT of 2,500 ms was reached. The cue and target disappeared immediately after a response. The ITI was always 300 ms. In the first part (composite condition) participants completed one block of 32 training trials followed by three blocks of 68 experimental trials.

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In the second part, the task cue appeared first followed by the target after a 500-ms delay (cue-first condition) or the target appeared first followed by the task cue after a 500-ms delay (target-first condition). Participants completed a block of 20 training trials followed by three experimental blocks of 68 trials under the cue-first condition and a block of 20 training trials followed by three experimental blocks of 68 trials under the target-first condition. In a previous study, participants were allowed to respond before the task cue onset during the target-first condition (Schneider & Logan, 2014a). However, this systematically changed the response-stimulus interval (RSI) between the target-first condition and the cue-first condition. In the cue-first condition the RSI was the sum of the ITI + cue-target interval, whereas in the target-first condition, where participants could make responses before the cue, the RSI was equivalent to the ITI. In order to keep the RSI constant in our experiment, participants were required to make their response after the onset of the task cue. Early responses were not registered and participants had to press the response key after onset of the task cue. After the experimental blocks, each participant was asked to report the strategy they had applied in each block of trials.

Results

We excluded all training trials from the data analyses. Before conducting ANOVAs on mean RTs and ERs, we ran binomial tests to check individual ERs against chance performance. The results indicated that 16 non-Chinese participants and two Chinese participants were unable to perform significantly better than chance in incongruent trials (their ERs ranged between 35% and 49%). Their data were excluded and the participants replaced in order to establish balanced samples of 16 non-Chinese and 16 Chinese participants in the two language groups. Mean RTs and ERs together with *SD*s for each language group and trial condition are F3 illustrated in Figure 3 and listed in the ~~Appendixes~~.

Analysis of RTs. A full-factorial four-way ANOVA with mixed effects was conducted to compare the mean RTs between T2 and within conditions (Table 2, Figure 3). The three within-subjects factors were trial transition (switch, repeat), congruency (congruent, incongruent) and stimulus order (composite, cue-first, and target-first). The between-subjects factor was language group (Chinese, non-Chinese).

There was no statistically significant main effect for trial transition nor any two-way interactions with trial transition. We observed a statistically significant three-way interaction between trial-transition, congruency, and stimulus order. In some condition, the trial-transition was reversed, which might explain the three-way interaction (~~i.e.,~~ switch − repeat <0; see ~~Appendixes~~).

For the factor of stimulus order, post hoc comparisons revealed that the mean RT in the cue-first condition (696 ms) was significantly shorter than in the composite condition (963 ms), $p < .001$, $d = 1.97$. In addition, the mean RT in the target-first condition (467 ms) was significantly shorter than in the cue-first condition, $p < .001$, $d = 1.64$. The mean RT in the target-first condition was also significantly shorter than in the composite condition, $p < .001$, $d = 3.04$. Moreover, post hoc comparisons suggested that target-first condition had significantly shorter RTs in both the congruent and the incongruent conditions compared with the cue-first condition: congruent, $p < .001$, $d = 1.85$; incongruent, $p < .001$, $d = 1.48$.

There was a statistically significant interaction between congruency and language group. Post hoc comparisons indicate that congruency had a significant effect in both the non-Chinese and the Chinese groups: non-Chinese ($p < .001$, $d = 1.20$); Chinese ($p < .001$, $d = 1.01$). The effect of congruency was larger in the non-Chinese group (incongruent − congruent = +344 ms) than in the Chinese group (incongruent − congruent = +246 ms).

There was also a significant interaction between congruency and stimulus order. Post hoc comparisons, suggested that congruency was significant in all three stimulus orders (all $p < .001$; effect size Cohen's d for composite, cue-first, and target-first condition was 1.80, 1.91, and 1.87, respectively). However, the congruency effect varied across different conditions. Further pairwise comparisons showed that in the composite (incongruent − congruent = +325 ms) and the target-first condition (incongruent − congruent = +337 ms) the congruency effect was equivalent, $p = .47$, $d = .07$. However, the congruency effect was significantly larger in the target-first condition than in the cue-first condition (incongruent − congruent = +222 ms), $p < .001$, $d = .98$. Furthermore, the congruency effect was significantly increased in the composite condition compared to the cue-first condition, $p < .001$, $d = .69$ (see Figure 3c). We also observed a significant three-way interaction between congruency, stimulus order, and language group.

Analysis of ERs. An equivalent four-way ANOVA with mixed effects was conducted on mean ERs between and within conditions (Table 2, Figure 4). Post hoc comparisons on stimulus F4 order showed that the ER in the composite condition (9.93%) was significantly higher than the ER in the cue-first and the target-first condition (5.58% and 4.93%, respectively): composite versus cue-first condition, $p < .001$, $d = 1.32$; composite versus target-first condition, $p < .001$, $d = 1.29$. However, the ER difference between the cue-first condition and the target-first condition was not significant, $p = .24$, $d = .18$.

There was a significant interaction between congruency and stimulus order. Post hoc comparisons revealed that the factor of congruency was significant in all three stimulus orders (all $p < .001$; effect size Cohen's d for composite, cue-first and target-first conditions was 2.75, 2.06, and 1.46, respectively). However, pairwise comparisons showed that the effect of congruency varied across conditions. The congruency effect for ERs was significantly greater in the composite condition (incongruent − congruent = 14.65%) than in the cue-first condition (incongruent − congruent = 9.86%) and the target-first condition (incongruent − congruent = +7.32%): composite versus cue-first condition, $p = .004$, $d = .67$; composite versus target-first condition, $p < .001$, $d = 1.02$. The difference between the cue-first and the target-first conditions was nonsignificant, $p = .08$, $d = .39$. Other interactions did not reach statistical significance ($p > .05$).

No switching costs. In Experiment 2A, none of the participants (Chinese and non-Chinese) showed switch costs, that is, they showed no statistically significant main effect of language group, trial transition nor two-way interactions with trial transition as factor. As a consequence of the absence of switching costs, we also did not observe the predicted interaction between stimulus sequence and language group.

We averaged the RT differences between switch and repeat trials across the three stimulus orders for each participant. In order to establish the odds between the null hypothesis (H_0) that partic-

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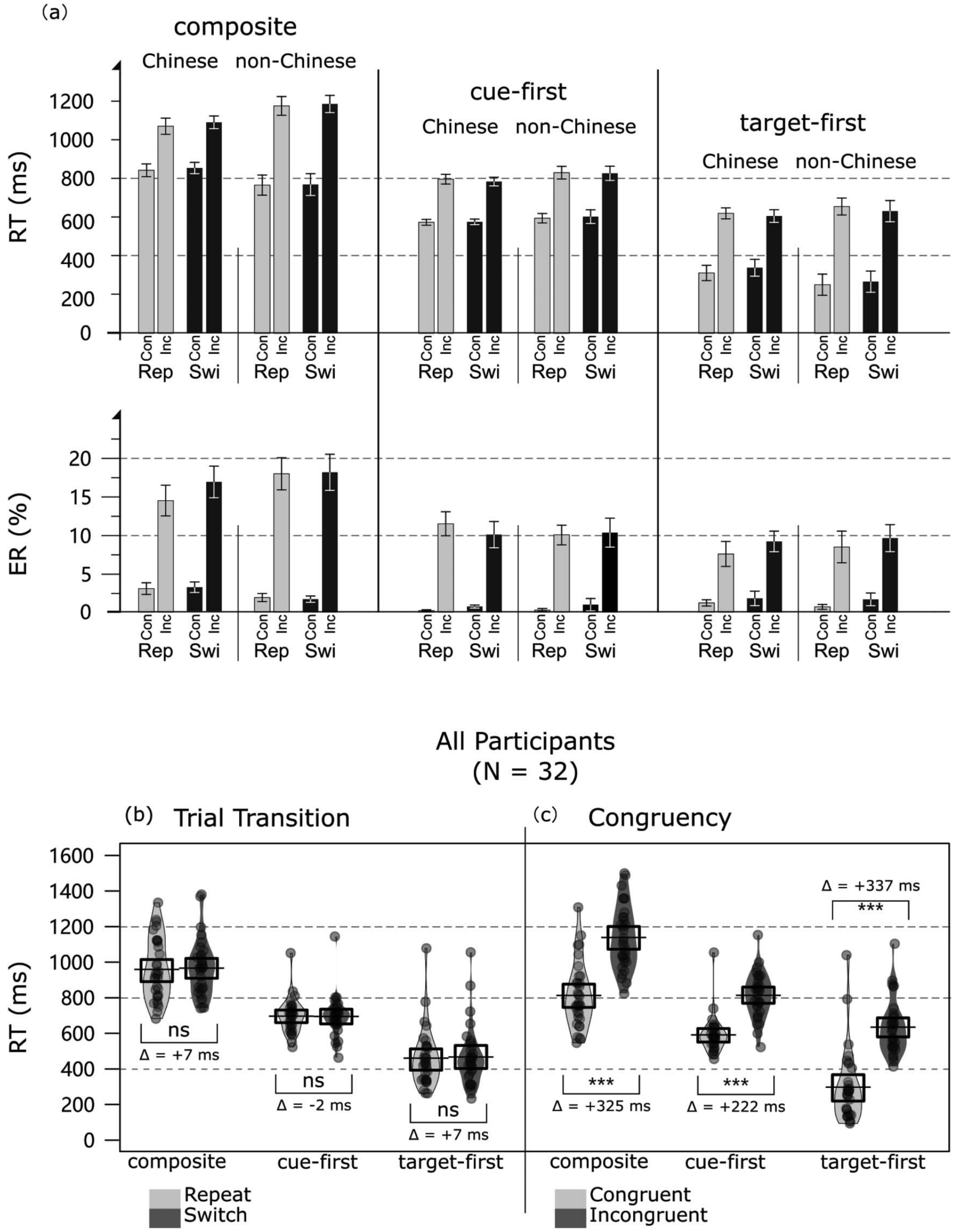

Figure 3. Results of Experiment 2A. (a) The bar graphs show mean RTs (top) and mean ERs (bottom) for each trial condition (repeat-congruent, repeat-incongruent, switch-congruent, switch-incongruent). The error bars indicate ±1 SEM. (b) The violin plots illustrate RT distributions for all participants (16 Chinese and 16 non-Chinese pooled) for repeat and switch trials and each stimulus order (composite, cue-first, and target-first condition). Jittered dots represent average RTs of participants. The black horizontal bar and the box represent the mean and 50% CI of the mean in each condition. (c) Violin plots illustrate RT distributions of congruent and incongruent trials for each stimulus order. Con = congruent; Inc = incongruent; Rep = repeat; Swi = switch. *** $p < .001$. *ns* = nonsignificant.

Table 2

Experiment 2A: Results of Two Mixed Effect ANOVAs on Mean RTs and ERs, Using Trial Transition (Repeat, Switch), Congruency (Congruent, Incongruent), and Stimulus Order (Composite, Cue-First, and Target-First) as Within-Subjects Factors, and Language Group (Target-First, Task Rule) as Between-Subjects Factor

	RT				ER			
Factor	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
L	.03	1, 30	.864	<.001	.04	1, 30	.850	.001
T	.50	1, 30	.484	.016	1.86	1, 30	.182	.058
C	216.84	1, 30	<.001	.878	132.50	1, 30	<.001	.815
S	224.51	2, 60	<.001	.882	23.43	2, 60	<.001	.438
L × T	.18	1, 30	.679	.005	.006	1, 30	.939	<.001
L × C	5.92	1, 30	.021	.165	.50	1, 30	.485	.015
L × S	.52	2, 60	.595	.017	.13	2, 60	.878	.004
T × C	2.17	1, 30	.151	.067	.24	1, 30	.627	.008
T × S	.50	2, 60	.604	.017	.85	2, 60	.431	.028
C × S	17.93	2, 60	<.001	.374	12.81	2, 60	<.001	.299
L × T × C	.004	1, 30	.951	<.001	.17	1, 30	.682	.006
L × T × S	.29	2, 60	.742	.009	.85	2, 60	.431	.028
L × C × S	8.13	2, 60	<.001	.213	1.31	2, 60	.276	.042
T × C × S	3.27	2, 60	.048	.098	.91	2, 60	.408	.029
L × T × C × S	.009	2, 60	.991	<.001	.39	2, 60	.678	.013

Note. L = language group; T = trial transition; C = congruency; S = stimulus order.

ipants had no switch costs and the alternative hypothesis (H_1) that participants had switch costs. The corresponding Bayes factor (Morey & Rouder, 2011) was 4.76, suggesting that the data were about five times more likely to be observed under H_0 than under H_1.

Self-reports. All participants, Chinese and non-Chinese, reported that they applied the target-first strategy throughout the experiment. According to their verbal reports, none of the participants was aware of the task rules.

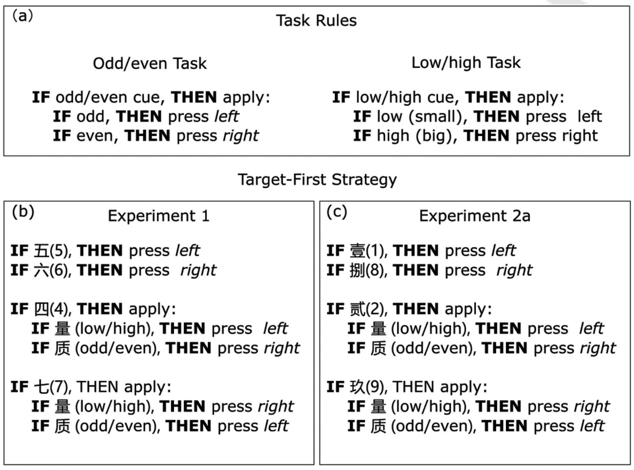

Figure 4. Overview of task rules and target-first strategy. (a) Typical task rules includes two sets of conjunctive rules. A participant needs to execute two nested IF–THEN statements to arrive at the correct response. (b) The target-first strategy for Experiment 1. If the number 五 (5) or 六 (6) is shown, then the participant only needs to apply a single IF–THEN rule or a simple target-response association. However, if the number 四 (4) or 七 (7) is shown, then the participant needs to execute two nested conjunctive rules that are similar to the task rules, however target and cue are exchanged. (c) The equivalent target-first strategy for Experiment 2A.

Discussion

Surprisingly, none of the Chinese participants reported that they applied the task rules. Therefore, inconsistent with our prediction, all 32 participants, including the Chinese participants, showed no significant task-switching costs (switch − repeat = +4 ms). The corresponding Bayes factor provides moderate evidence (Jeffreys, 1961) in favor of the null hypothesis, suggesting that participants generated no task-switching costs in Experiment 2.

Even though participants indicated in their self-reports that they had no understanding of the task rules, we did not confirm the prediction by Forrest (2012) and Forrest et al. (2014) that task-switching costs would remain significant. However, in agreement with Experiment 1, we replicated the absence of task-switching costs in RTs and ERs in the non-Chinese group.

All participants performed better in the cue-first condition and the target-first condition than in the composite condition, as demonstrated by shorter RTs and lower ERs. The reductions in RT and ER may reflect a practice effect since all participants completed the composite condition first. When piloting the study, we initially counterbalanced all three conditions, but non-Chinese participants struggled to perform, particularly when the cue-first or target-first condition was administered first. Participants performed better when they first completed the composite condition. Therefore, we only counterbalanced the order of the cue-first and target-first condition across participants.

A disadvantage of using traditional Chinese numbers as target stimuli was that non-Chinese participants found it very difficult to memorize the cue-stimulus combinations. Half of the non-Chinese participants in Experiment 2A had to be replaced because their ERs in incongruent trials were too close to chance. In contrast, most Chinese participants, except for two, had reasonable ERs in

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incongruent trials. In future studies it may be beneficial to extend the training sessions so that participants with no prior knowledge of the cues and target stimuli stay below a suitable error rate. However, extensive training of participants may introduce other issues when measuring switch costs (Zhao, Wang, & Maes, 2018) that may obscure differences between language groups.

Another finding of Experiment 2A is the difference in performance between the cue-first and the target-first condition. In the target-first condition, participants had significantly shorter RTs than in the cue-first condition. RTs were significantly reduced in both congruent and incongruent trials. Because all 32 participants reported that they applied the target-first strategy throughout the experiment we can assume that participants had a strong tendency to first process the target stimuli at the bottom of the cue-target display. In congruent trials, participants who applied the target-first strategy directly associated a response with the congruent target stimulus as soon as it was shown, resulting in shorter RTs and lower ERs as also demonstrated by others (Ruge et al., 2009; Schneider & Logan, 2014a).

In incongruent trials, the target-first strategy allowed participants to engage in "target-based" preparations. Participants' target-first strategy may be represented by a set of nested conjunctive rules in order to infer the correct response in incongruent trials: An initial IF–THEN statement followed by one of two possible If–THEN statements (see Figure 4b and 4c). We propose that after processing the first IF–THEN statement, participants may have prepared the two possible IF–THEN statements in advance. This preparation would be sufficient to give a correct response more quickly and more accurately in the target-first compared to the cue-first condition.

Preparation in terms of IF–THEN statements is not a novel idea. In previous studies a similar explanation has been offered for cue-based preparation (Woodward, Meier, Tipper, & Graf, 2003). Although there is no agreement on the definition of a task set (Schneider & Logan, 2014b), Woodward, Meier, Tipper, and Graf (2003) suggested that the task set may be considered as a set of conjunctive rules or IF–THEN statements so that, as soon as the task cue is presented, participants can start preparing all possible IF–THEN statements (Woodward et al., 2003; see Figure 4a).

In Experiment 2A, none of the participants applied the task rules, resulting in virtually no switching costs in RTs and ERs. This makes it difficult to compare our results in the target-first condition with studies where participants were instructed to use the task rules. When participants were instructed to use the task rules, the target-first condition did not help performance in incongruent trials. In the studies by Schneider and Logan (2014a), where participants applied task rules, they responded in congruent trials more than 200 ms faster in the target-first compared with the cue-first condition. However, in incongruent trials the mean difference in RTs between target-first and cue-first condition was reduced to less than 50 ms. Moreover, Ruge, Braver, and Meiran (2009) reported that RTs in incongruent trials were on average 82 ms longer in the target-first condition than in the cue-first condition. In order to compare the effect of the target-first strategy with the effect of task rules on task-switching we conducted Experiment 2B. We explicitly instructed a new sample of Chinese participants to apply the task rules and observed their performance in the target-first and cue-first condition.

Experiment 2B

In order to establish switch costs and congruency effects when the task rules are made explicit, we invited a new sample of Chinese students to perform the same tasks as in Experiment 2A. This time, however, the participants were instructed to apply the task rules. We sought to compare the results of the newly recruited Chinese participants with the results of the Chinese participants from Experiment 2A. In addition, we tried to replicate the results of the Chinese language group in Experiment 1.

Because we made the task rules explicit, we predicted that participants would show significant switch costs in Experiment 2B. According to Schneider and Logan (2014a) the task rules should be more prominent in the cue-first condition than in the target-first condition, leading to increased switch costs in the cue-first condition. Although the newly recruited Chinese participants were instructed to use the task rules, we predicted that Chinese participants may also use simple target-response associations in congruent trials. This prediction is based on the results in Ruge et al. (2009) and in Schneider and Logan (2014a). Therefore, we expected reduced RTs and ERs for congruent trials but not for incongruent trials in the target-first condition.

Method

Participants. A total of 17 Chinese participants (female = 14; mean age = 23, *SD* = 2.00) from the University of Glasgow participated. Data from 16 participants were included in the analyses since one participant did not perform better than chance. Each participant received £4 for taking part and was naive to the tasks and purpose of the experiment.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were identical to Experiment 2A except that the task rules were explained to the Chinese participants during instructions.

Results

One participant did not perform better than chance in the incongruent trials of the composite condition (ER 38%). This participant was replaced to achieve balanced numbers of new Chinese participants and the Chinese participants from Experiment 2A. The mean RTs and ERs with *SEMs* and *SD*s for each trial condition are illustrated in Figure 5a and listed in the ~~Appendixes~~, respectively. F5 The data from this new sample were analyzed together with the data of the 16 Chinese participants in Experiment 2A who received no instructions about the task rules.

Analysis of RTs. A four-way ANOVA with mixed effects was conducted to compare mean RTs in a full factorial design. The three within-subjects factors were trial transition (switch, repeat), congruency (congruent, incongruent), and stimulus order (composite, cue-first, and target-first). The between-subjects factor was strategy group (Chinese participants who used the target-first strategy in Experiment 2A, Chinese participants who used task rules in Experiment 2B). The results of this analysis are summarized in Table 3. T3

For the significant main effect of stimulus order, post hoc pairwise comparisons showed that the mean RT in the cue-first condition (708 ms) was shorter than the mean RT in the

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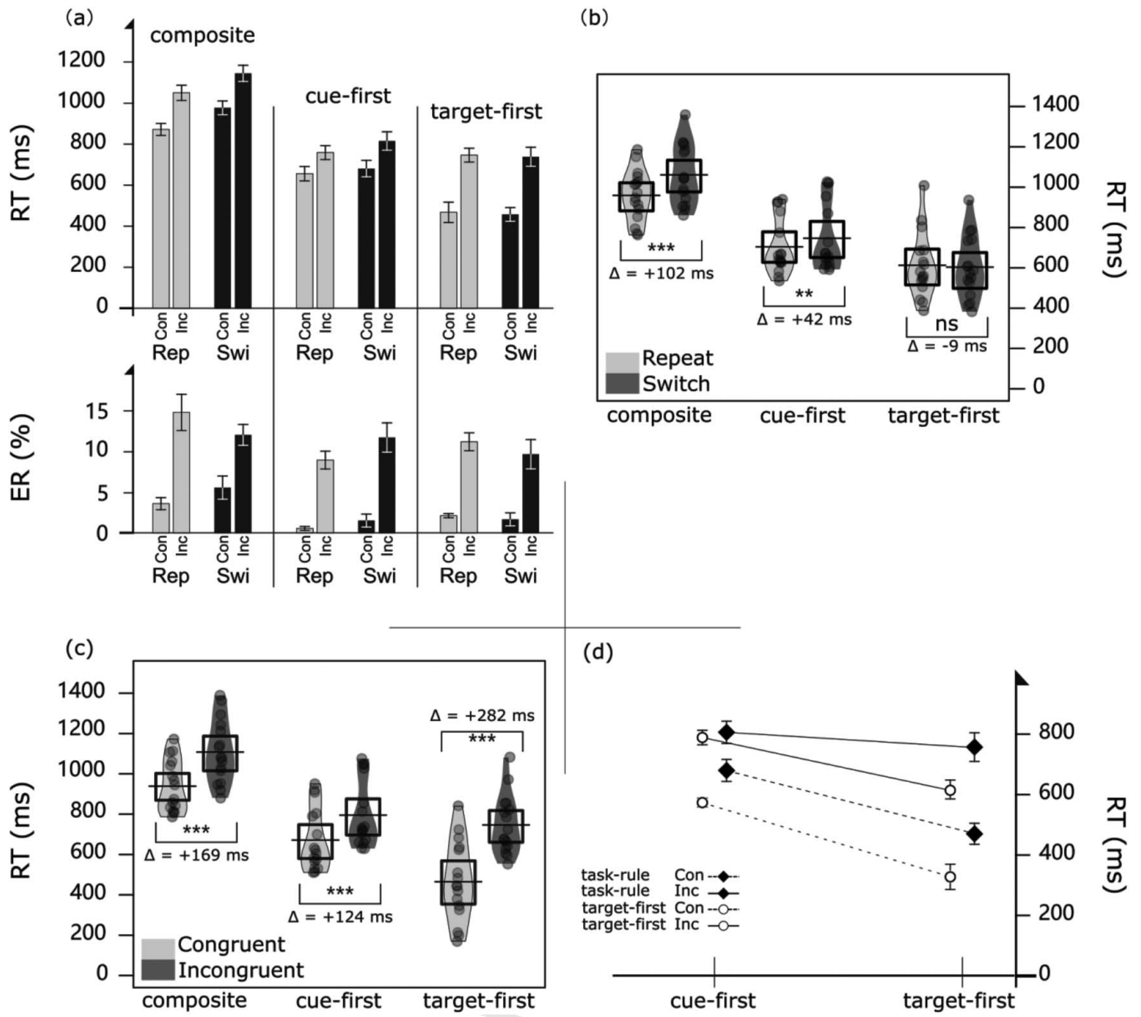

Figure 5. Results of Experiment 2B for 16 Chinese participants receiving task rule instructions. (a) The bar graphs show mean RTs (top) and mean ERs (bottom) for each trial condition (repeat-congruent, repeat-incongruent, switch-congruent, switch-incongruent). The error bars indicate ±1 SEM. (b) The violin plots illustrate the RT distributions of the Chinese participants for repeat and switch trials. Overlaid jittered dots represent the average RTs of each participant. The black horizontal bar and the box around it represent the mean and 50% CI of the mean for each condition, respectively. (c) Violin plots illustrate RT distributions for congruent and incongruent trials. (d) The line graph illustrates the interaction between strategy group and stimulus order. Mean RTs in congruent trials (dashed lines) and incongruent trials (solid lines) are shown for task rule group (filled circle) and target-first group (open circle). The error bars indicate ± 1 SEM. Con = congruent; Inc = incongruent; Rep = repeat; Swi = switch. *** $p < .001$. ** $p < .01$. * $p < .05$. *ns* = nonsignificant.

composite condition (997 ms), $p < .001$, $d = 2.31$. In addition, for the mean RT in the target-first condition (533 ms) was significantly shorter than the mean RT in the cue-first condition, $p < .001$, $d = 1.23$, as well as in the composite condition, $p < .001$, $d = 3.19$.

There were two-way interactions between trial transition and strategy, and between trial transition and stimulus order (see Table 3). There was also a significant three-way interaction between trial transition, stimulus order, and strategy. In order to better interpret these three-way interactions, we analyzed the RTs for the target-first group and the task rule group separately.

First, we only found significant switch costs in the group that applied the task rules (Experiment 2B), $F(1, 15) = 34.13$ $p < .001$, $\eta_p^2 = .696$. Second, in the group that used the target-first strategy (Experiment 2A), the interaction between trial transition and stimulus order was not significant, $F(2, 30) = 1.97$, $p = .180$. In the task rule group, the interaction between trial transition and stimulus order was significant, $F(2, 30) = 11.58$, $p < .001$, $\eta_p^2 = .436$, because switch costs varied across different stimulus orders. Post hoc comparisons showed that trial transition had a significant effect in the composite condition (switch − repeat = +102 ms, $p < .001$, $d = .74$). Although halved in size in the cue-first condition, switch costs were still present (switch − repeat = +42 ms, $p = .005$. $d = .27$). In the target-first condition, however, the task-switching costs were no longer significant (switch − repeat = −9 ms, $p = .50$, $d = .008$; see Figure 5b).

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Table 3

Experiment 2B: Results of Two ANOVAs With Mixed Effects on Mean RTs and ERs, Using Trial Transition (Repeat, Switch), Congruency (Congruent, Incongruent), and Stimulus Order (Composite, Cue-First, and Target-First) as Within-Subjects Factors, and Strategy (Target-First, Task Rule) as Between-Subjects Factor

	RT				ER			
Factor	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
ST	3.67	1, 30	.065	.109	.11	1, 30	.743	.004
T	23.69	1, 30	<.001	.441	1.00	1, 30	.325	.032
C	198.88	1, 30	<.001	.869	127.68	1, 30	<.001	.810
S	197.17	2, 60	<.001	.868	20.25	2, 60	<.001	.404
ST × T	14.21	1, 30	<.001	.321	.28	1, 30	.603	.009
ST × C	3.15	1, 30	.086	.095	.44	1, 30	.515	.014
ST × S	2.46	2, 60	.094	.076	.80	2, 60	.452	.026
T × S	.14	1, 30	.711	.005	.48	1, 30	.494	.016
ST × S	8.04	2, 60	<.001	.211	.17	2, 60	.842	.006
C × S	14.88	2, 60	<.001	.332	3.20	2, 60	.047	.096
ST × T × C	1.17	1, 30	.289	.037	2.31	1, 30	.138	.072
ST × T × S	5.51	2, 60	.006	.155	2.75	2, 60	.071	.084
ST × C × S	2.07	2, 60	.135	.064	2.45	2, 60	.095	.076
T × C × S	.48	2, 60	.624	.016	.23	2, 60	.798	.007
ST × T × C × S	.84	2, 60	.438	.027	3.19	2, 60	.048	.096

Note. ST = strategy; T = trial transition; C = congruency; S = stimulus order.

Analysis of ERs. A corresponding four-way ANOVA with mixed effects was conducted on the mean ERs. The results of this analysis are summarized in Table 3. There was a significant interaction between congruency and stimulus order. Post hoc comparison showed that the congruency effect was statistically significant in all three stimulus orders (all $p < .001$; Cohen's *d* for composite, cue-first and target-first condition was 2.09, 2.23, and 1.79, respectively) but varied among the three stimulus orders. Pairwise comparisons showed that the congruency effect was significantly larger in the composite condition (incongruent − congruent = +10.7%) than in the cue-first condition (incongruent − congruent = +9.8%), $p = .004$, $d = .14$. Moreover, the effect of congruency was significantly larger in the composite condition than in the target-first condition (incongruent − congruent = +7.59%, $p < .001$, $d = .51$). The effect of congruency was not significantly different between the cue-first and target-first condition ($p = .076$, $d = .36$). The four-way interaction also reached significance.

Comparing cue-first with target-first condition. We made specific predictions about the cue-first condition and the target-first condition due to the use of the target-first strategy and task rules. The results of Experiment 2A indicate that participants who employed the target-first strategy, had reduced RTs in the target-first condition for both congruent and incongruent trials compared with the cue-first condition. In Experiment 2B, we predicted that participants who employed the task rules, should have reduced RTs in the target-first condition for congruent but not for incongruent trials.

In order to examine this prediction, we compared the RT differences between cue-first and target-first condition. The corresponding *t* tests show that participants who applied the target-first strategy performed significantly faster in the target-first than in the cue-first condition for incongruent trials (incongruent cue-first − incongruent target-first = 792 − 617 = +175 ms; $p < .001$, $d = 1.48$). However, this difference was not significantly different when participants applied the task rules (incongruent cue-first − incongruent target-first = 795 − 747 = +48 ms; $p = .094$, $d = .31$; see Figure 4d). Equivalent pairwise comparisons of ERs gave nonsignificant results ($p > .05$).

Self-report. In the composite and the cue-first condition, all newly recruited Chinese participants followed the instructions and reported that they mostly applied the task rules. In the target-first condition, however, they noticed after a certain number of trials that in congruent trials the task cue was irrelevant. As a consequence, they started to apply the target-first strategy and/or alternated between the target-first strategy and task rules.

Discussion

As predicted, task-switching costs depend on the use of task rules and emerged in the composite and cue-first condition but not in the target-first condition. Schneider and Logan (2014a) reported comparable results. In their first experiment, the task-switching costs were also larger in the cue-first condition than in the target-first condition. In our Experiment 2B, the Chinese participants reported that they noticed in congruent trials of the target-first condition that responding to the target only was more efficient than applying the task rules and therefore started to use target-response associations in combination with the task rules. This may explain why the task-switching costs were reduced and no longer significant in the target-first condition.

In a typical task-switching paradigm, participants may not facilitate target-response associations because the task-rule instructions tell them to consider the cue before categorizing target features. However, in congruent trials of the target-first condition, this shortcut between target and correct response became obvious and almost impossible to ignore. In contrast, a correct response in an incongruent trial required processing of the task cue and the target stimulus, regardless of the sequence of the cue and target. Thus, in incongruent trials of the cue-first and target-first condition, participants most likely followed the task-rule instructions.

Because participants used target-response associations in congruent trials, they were able to respond more quickly to congruent targets in the target-first condition than in the cue-first condition. Thus, in congruent trials of the target-first condition participants could select the correct response before the task cue appeared (Ruge et al., 2009; Schneider & Logan, 2014a).

The participants in Experiment 2A were able to respond more quickly to incongruent targets in the target-first condition compared to incongruent targets in the cue-first condition. This difference between incongruent trials was largely reduced and no longer significant when participants received the task-rule instructions in Experiment 2B. Because RTs in the target-first condition were overall slower in Experiment 2B than in 2A but very similar for the cue-first condition, we suggest that participants in Experiment 2A had an advantage in the target-first condition when applying the target-first strategy. They could always use the target to select a response directly or to prepare the two possible rules, leading to faster responses. Conversely, participants in Experiment 2B learned and applied the task rules which required to process the task cue first. In the target-first condition, and for incongruent trials in particular, participants may have waited for the cue onset before they prepared the response. As a result, they did not take advantage of the early target presentation in the target-first condition as the participants in Experiment 2A.

In the incongruent trials of the cue-first condition participants who applied the task rules in Experiment 2B did not respond faster (795 ms) than participants who applied the target-first strategy in Experiment 2A (793 ms). Although the task rules suggest cue-based preparation in the cue-first condition, any advantage from this preparation might be offset by the additional step of feature categorization. The task-rules require feature categorization when applying the conjunctive rules (Figure 4a), because participants need to categorize the task-relevant features (odd/even or low/high) from the target number, which may delay the response (Schneider, 2015, 2017). In contrast, the conjunctive rules of the target-first strategy do not require such a feature categorization.

In Experiment 2B, we observed significant RT congruency effects in all three stimulus conditions. Because the newly recruited Chinese participants were instructed to use the task rules, we can rule out that the RT congruency effect disappeared in Experiment 1 because participants applied the task rules to Chinese numerals. Further investigations may be necessary to clarify why Chinese participants had no significant RT congruency effect (but a significant ER congruency effect) in Experiment 1 but persistent RT congruency effects in Experiment 2A and 2B.

General Discussion

In two experiments we demonstrated that switch costs are eliminated when participants have no opportunity to apply the task rules. We believe that this is the first comprehensive demonstration of eliminating task-switching cost in humans using bivalent stimuli in a standard task-switching paradigm.

Forrest (2012) and Forrest et al. (2014) proposed an associative learning account in order to explain reduced task-switching costs. They suggested that in a conventional task-switching experiment, human participants may combine associative learning with cognitive learning, but if they do not apply task rules then they can only fall back on associative learning. Associative learning would then be responsible for any remaining task-switching costs (Forrest, 2012; Forrest et al., 2014).

Our results are not compatible with an associative learning account for two reasons. First, in our experiments task-switching costs were completely eliminated when participants could not apply the task rules to the bivalent target stimuli. Second, our findings indicate that participants processed information according to the target-first strategy. In incongruent trials of the target-first condition, participants—who applied the target-first strategy—engaged in target-based preparation and outperformed participants who received instructions according to the task rules. Thus, the idea that human participants, who do not apply the task rules, always resort to associative learning by default, is questionable. Although associative learning may take place in congruent trials, participants are likely to use rule-based strategies in incongruent trials. As a possible explanation of previous results, we suggest that in many task-switching studies, the strategies of the participants may have not been adequately controlled and reported. In other words, although participants were unable to verbalize the task rules, they may have been able to use them implicitly, thereby introducing switch costs.

The results of Experiment 2A demonstrate that Chinese participants, who did not verbalize the task rules, displayed no task-switching costs in any of the conditions. This contrasts with results of studies in which task-switching costs remained significant even though participants could not verbalize the task rules (Forrest, 2012; Forrest et al., 2014). We speculate that in these studies some of the participants were able to facilitate task-relevant features of Arabic numbers in the parity and magnitude task. Arabic numbers are typically used in arithmetic operations and therefore participants may have used the task rules implicitly but were unable to state them explicitly. Chinese numerals, however, and especially traditional Chinese numerals, are rarely used for arithmetic operations and the Chinese participants in Experiment 2A did not exploit their task-relevant features. They used the target-first strategy rather than task rules and therefore showed no task-switching costs. If the Chinese participants had first solved arithmetic problems with traditional Chinese numerals before they performed in the number tasks, then this may have increased their awareness for task-relevant features, possibly triggering the use of task rules and inducing switch costs.

Strategies in Task-Switching

In studies with univalent stimuli it has been demonstrated that CTR associations can eliminate task-switching costs (Dreisbach et al., 2006, 2007; Dreisbach & Haider, 2008). Therefore, it is important to compare our results with the findings reported by Dreisbach et al. (2006, 2007) and Dreisbach and Haider (2008).

Dreisbach et al. (2006, 2007) and Dreisbach and Haider (2008) employed univalent stimuli resulting in no incongruent trials. They reported that participants who applied the CTR approach had shorter RTs than participants who applied the task rules. Here we employed bivalent targets but observed similar results in the congruent trials. In Experiment 1, non-Chinese participants, who applied the target-first strategy, responded faster in the congruent trials than Chinese participants, who applied the task rules (774 ms vs. 993 ms). In addition, in Experiment 2A Chinese participants who applied the target-first strategy responded faster in the congruent trials than Chinese participants who used the task rules in Experiment 2B (587 ms vs. 691 ms).

It has been suggested that participants might use different response selection routes. According to Schneider (2015, 2017), participants who apply task rules follow a mediated route of response selection. For example, participants in Experiment 2B may have categorized features according to the task rules before they selected a response to that feature (e.g., 质 + 玖 ⇒ odd ⇒ left). In contrast, when participants applied the target-first strategy or CTR associations, they may have followed a nonmediated route of response selection (Schneider & Logan, 2015). The nonmediated route is quicker because the response can be selected directly through target-response association and does not require categorization of target features in an additional processing step.

We also observed a difference in ERs for Experiment 1. Non-Chinese participants had a higher mean ER than Chinese participants. However, this is most likely the result of non-Chinese participants having difficulties in processing the unfamiliar Chinese characters rather than differences in strategy. In Experiments 2A and 2B, Chinese participants who applied the target-first strategy and the task rules, respectively, had no significant difference in ERs compared with non-Chinese participants.

Furthermore, we agree with Dreisbach et al. (2006, 2007) and Dreisbach and Haider (2008) that participants prefer task rules over CTR associations. For example, in Dreisbach et al. (2007) participants, who mastered CTR associations and had no task-switching costs, showed task-switching costs as soon as the task rules were introduced. Participants preferred the task rules even though there was no demand to actually employ them. In addition, when participants applied the task rules rather than CTR associations their performance was less efficient.

When applying the task rules was not possible, participants created the target-first strategy, an alternative rule-based strategy, rather than defaulting to CTR associations. We argue that in real-life situations stimuli, viewing conditions and contexts can change quickly, so that a response to a cognitive task needs to be associated with a large number of different stimulus representations. Thus, as a default, pursuing flexible rule-based strategies can be a more efficient approach because it requires less practice and reduces uncertainty in complex and dynamic environments. However, for repetitive tasks and severe time constraints, applying rules rather than associations may be disadvantageous as the responses require longer RTs (Ariely & Zakay, 2001).

Task-Switching in Pigeons and Monkeys

We successfully demonstrated that eliminating task-switching costs for bivalent target stimuli can be extended from pigeons (Meier et al., 2013; Meier et al., 2016) to human participants. However, rather than concluding that pigeons and humans showed no switch costs because they both used CTR associations, we propose that participants developed an alternative rule-based strategy that can eliminate task-switching costs.

In Experiment 2B, we found that even with knowledge of the task rules, task-switching costs were eliminated once participants realized the advantage of the rule-based strategy in the target-first condition. This observation provides an alternative explanation for task-switching results in monkeys. Monkeys can also perform task-switching without showing any significant task-switching costs (Avdagic et al., 2014; Stoet & Snyder, 2003, 2004). However, unlike pigeons which may not be able to apply task rules (Meier et al., 2013; Meier et al., 2016; but see Castro & Wasserman, 2016; Soto & Wasserman, 2010) various studies demonstrated that monkeys do have executive control abilities and can apply rule-based strategies (Avdagic et al., 2014; Stoet & Snyder, 2004). We therefore suggest that monkeys might have applied a target-first strategy similar to the non-Chinese participants in Experiment 1 and the participants in Experiment 2A. In fact, although the task-switching costs were eliminated in monkeys, they showed larger congruency effects than human participants who applied task rules (Stoet & Snyder, 2003). Similarly, in our experiments, participants who applied the target-first strategy showed stronger congruency effects than participants who applied the task rules.

Reconfiguration and Interference

At a first glance, our findings support the task set reconfiguration account of task-switching (Meiran, 2000; Monsell & Mizon, 2006; Rogers & Monsell, 1995). When participants applied the target-first strategy instead of the task rules, they no longer switched between two tasks (the odd/even task and the low/high task). Therefore, there was no task set reconfiguration process involved and task-switching costs were eliminated. A similar interpretation has been offered in studies on pigeons (Meier et al., 2013; Meier et al., 2016). Meier and colleagues suggested that pigeons do not have executive control (however, see Castro & Wasserman, 2016; Soto & Wasserman, 2010) and therefore cannot exhibit task-switching costs. Task-switching costs can only emerge when participants employ executive control as in task-set reconfiguration (Meier et al., 2016). However, this explanation ignores the possibility that subjects, who do not apply the task rules, may not experience proactive interference from preceding trials (Li, Li, Lages, & Stoet, 2017).

For example, it was suggested that interference may originate from "stimulus-task-set associations" (Koch & Allport, 2006; Waszak & Hommel, 2007; Waszak, Hommel, & Allport, 2003). In other words, when a target stimulus is shown in a task, the stimulus may form an association with the relevant task set. In these studies, both tasks may share the same stimuli (Koch & Allport, 2006; Waszak & Hommel, 2007; Waszak et al., 2003). Therefore, in switch trials, when the previous stimulus is repeated but the task set is switched, the previous stimulus-task-set association can interfere with the current stimulus-task-set association, resulting in task-switching costs. It is possible that both task-set reconfiguration as well as proactive interference is eliminated when participants apply the target-first strategy.

Furthermore, Woodward et al. (2003) proposed that proactive interference can also occur between task-relevant features. According to this account, the task performed on trial $n - 1$ (e.g., an odd/even task) requires the activation of one feature-response mapping from the target stimulus (e.g., odd ⇒ left), while inhibiting or negatively priming another feature-response mapping (e.g., larger number ⇒ right). If, however, the inhibited or negatively primed mapping is required on the subsequent trial n, additional time is needed to reactivate it, and this results in task-switching costs. This implies that interference only occurs if both task-relevant features are activated or processed at the same time. When participants applied the task rules, they had to pay attention to both task-relevant features. Alternatively, when participants applied the target-first strategy, they might not activate all task-relevant features. In particular, it was effectively impossible for non-Chinese participants in Experiment 1 and Experiment 2A to process the task-relevant features of the Chinese numerals. As a result, both task-set reconfiguration as well as proactive interference were irrelevant and the task-switching costs were eliminated.

Implications for the Compound-Retrieval Account

Our findings are difficult to reconcile with theoretical accounts that try to explain task-switching costs in terms of memory and retrieval from memory. The compound-cue retrieval account suggests that in a typical task-switching experiment, switch costs are not just produced by "endogenous" control operations triggered by the task rules; at least a portion of the costs result from a compound retrieval process. Participants can form cue-target compounds and retrieve the correct response for each compound directly from memory. Because the cue also switches in task-switching trials, a proportion of task-switching costs may be due to an additional cue-encoding process or cue-switching costs that contribute to the observed task-switching costs (Logan & Bundesen, 2003; Logan & Schneider, 2010; Schneider & Logan, 2005, 2007).

The compound-cue retrieval account would predict that in Experiments 1, 2A, and 2B the switching costs should remain significant regardless of the approach participants apply because the additional "cue-encoding process" is not the result of rule-based strategies. However, our results show that no task-switching costs were observed when participants applied the target-first strategy. The compound-cue retrieval account is therefore incompatible with our results.

In previous studies it was demonstrated that cue-switching costs originate from an active control process, rather than from encoding the cue itself (Logan & Bundesen, 2003; Schneider & Logan, 2005). For example, it was suggested that cue-switching costs reflect the activation of the task set representations in working memory (Grange & Houghton, 2010; Mayr & Kliegl, 2003). If cue-switching costs are present, we therefore propose that these may be by-products of applying the task rules. When applying task rules, participants need to encode the task cue and categorize a target accordingly. As a consequence, the cue-encoding process requires additional cognitive effort and cue-switching costs occur (Grange & Houghton, 2010; Mayr & Kliegl, 2003). However, when participants apply alternative strategies, such as the target-first strategy, the task cue may no longer signal task-relevant information. Thus, the cue-encoding process becomes simpler and no longer produces discernable cue-switching costs.

Conclusion

By manipulating the meaningfulness of cue and target stimuli between Chinese and non-Chinese participants, we have shown that it is possible to eliminate task-switching costs in a standard task-cueing paradigm with bivalent target stimuli. In previous studies, language proficiency has featured as a covariate of task switching (Declerck, Grainger, Koch, & Phlipp, 2017). In one study researchers also employed Chinese characters as stimuli (Campbell, 2005) but to the best of our knowledge the present study is the first that used a language barrier in order to control the use of task rules in task switching.

In two control experiments we demonstrated that participants, who did not employ the task rules, did not simply revert to associative learning. Instead, participants developed alternative strategies that use target-response association in congruent trials and rule-based strategies in incongruent trials. As discussed by Meier et al. (2013, 2016), it is difficult to control participants' response strategies, presumably because participants try to reduce cognitive effort and uncertainty by developing strategies that prioritize goal-relevant information (Cooper et al., 2015; Mackie, van Dam, & Fan, 2013). We conclude that the target-first strategy, as identified in Experiment 2A, exemplifies an alternative rule-based strategy that requires some executive control but generates no or negligible task-switching costs because the same set of rules can be applied to both switch trials as well as repeat trials. It seems possible that the absence of task-switching costs, as reported in monkeys, may also be related to the use of simplified response strategies as observed here.

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(*Appendices follow*)

tapraid5/zfv-xlm/zfv-xlm/zfv99918/zfv3815d18z | xppws | S=1 | 1/14/19 | 1:31 | Art: 2018-0349

Appendix A

AQ: 3

Experiment 1: Means (SD) of RT ms and ER % of Each Trial Condition and Language Group in Block 1–2 and Block 3–4

	Chinese (N = 24)				Non-Chinese (N = 24)			
	RT (ms)		ER (%)		RT (ms)		ER (%)	
Block 1–2	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Repeat Congruent	969	172	5.51	5.99	792	143	5.96	5.09
Repeat Incongruent	978	203	10.40	9.04	1031	173	22.12	9.30
Switch Congruent	1,088	200	6.80	6.91	819	118	5.72	5.75
Switch Incongruent	1,100	191	10.94	7.46	1007	155	19.47	9.03
Repeat	972	171	8.02	6.52	901	143	14.31	5.15
Switch	1,087	172	8.80	5.52	903	127	12.70	6.10
Congruent	1,036	180	6.28	6.06	809	124	5.81	4.83
Incongruent	1,044	183	10.75	6.99	1018	161	20.51	6.99
Total	1,037	166	8.49	5.47	902	130	13.24	4.34
	RT (ms)		ER (%)		RT (ms)		ER (%)	
Block 3–4	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Repeat Congruent	892	155	3.71	4.74	769	144	3.76	4.79
Repeat Incongruent	910	149	6.79	7.63	930	173	12.22	7.96
Switch Congruent	993	165	4.22	6.08	732	118	5.12	6.41
Switch Incongruent	984	151	8.41	7.35	913	155	9.88	6.72
Repeat	903	140	5.27	4.69	845	143	8.16	4.90
Switch	989	148	6.26	5.76	826	127	7.42	5.32
Congruent	953	155	4.03	4.73	748	124	4.49	4.99
Incongruent	949	140	7.52	5.82	921	161	10.92	5.57
Total	952	138	5.71	4.76	833	130	7.75	4.43
	RT (ms)		ER (%)		RT (ms)		ER (%)	
All Blocks	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Repeat Congruent	931	153	4.57	5.28	777	120	4.88	3.96
Repeat Incongruent	941	163	8.47	6.86	975	187	16.88	6.15
Switch Congruent	1,036	167	5.44	5.68	777	146	5.44	5.34
Switch Incongruent	1,038	148	9.53	5.75	956	171	14.31	5.45
Repeat	969	146	6.50	5.37	871	139	11.05	3.73
Switch	1,036	151	7.51	5.30	862	141	9.91	4.41
Congruent	993	157	5.06	5.37	774	130	5.13	4.32
Incongruent	993	148	9.00	5.15	963	173	15.39	4.30
Total	993	144	7.01	5.04	865	137	10.34	3.33

(*Appendices continue*)

APA NLM
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Appendix B

Experiment 2a: Mean (SD) of RT ms and ER % of Each Trial Condition, Cue-Stimulus Orders, and Language Group

	Chinese (N = 16)		Non-Chinese (N = 16)		All Participants (N = 32)	
Com	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)
Rep Con	845 (142)	3.03 (3.27)	758 (215)	1.76 (2.31)	806 (185)	2.45 (2.86)
Rep Inc	1,073 (178)	14.43 (8.20)	1,157 (217)	17.83 (8.28)	1,125 (196)	16.16 (8.42)
Swi Con	857 (127)	3.10 (2.96)	765 (230)	1.74 (1.83)	814 (192)	2.40 (2.55)
Swi Inc	1,093 (141)	16.75 (8.45)	1,167 (203)	18.07 (9.30)	1,141 (171)	17.44 (8.92)
Rep	960 (143)	9.18 (4.71)	939 (202)	9.51 (4.21)	957 (172)	9.41 (4.45)
Swi	966 (112)	10.14 (4.97)	950 (202)	10.23 (4.94)	964 (160)	10.21 (4.95)
Con	853 (120)	3.06 (2.29)	763 (221)	1.74 (1.84)	812 (183)	2.42 (2.17)
Inc	1,087 (156)	15.81(6.43)	1,164 (203)	18.24 (8.39)	1,137 (178)	17.07 (7.61)
Total	964 (118)	9.69 (3.91)	947 (201)	10.08 (4.31)	963 (160)	9.94 (4.12)
C-first	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)
Rep Con	575 (71)	.18 (.74)	591 (106)	.22 (.93)	586 (90)	.21 (.84)
Rep Inc	799 (111)	11.43 (6.69)	830 (137)	10.98 (6.55)	816 (125)	10.72 (6.00)
Swi Con	578 (67)	.60 (1.10)	599 (148)	.93 (3.34)	591 (116)	.80 (2.52)
Swi Inc	786 (100)	10.06 (7.28)	825 (153)	11.62 (9.24)	808 (131)	10.19 (7.40)
Rep	680 (77)	5.95 (3.57)	704 (114)	5.66 (3.39)	695 (97)	5.60 (3.29)
Swi	675 (73)	5.43 (3.86)	706 (140)	6.42 (5.21)	693 (113)	5.50 (4.16)
Con	577 (66)	.40 (.61)	598 (131)	.66 (2.10)	590 (104)	.55 (1.57)
Inc	792 (102)	10.44 (6.71)	828 (144)	11.53 (7.94)	812 (127)	10.42(6.56)
Total	679 (73)	5.50 (3.93)	707 (129)	6.18 (4.28)	696 (106)	5.58 (3.55)
T-first	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)
Rep Con	313 (168)	1.18 (1.91)	263 (226)	.92 (1.80)	283 (200)	.92 (1.73)
Rep Inc	622 (124)	7.51(6.19)	657 (180)	8.68 (8.25)	639 (157)	7.97 (7.30)
Swi Con	340 (185)	1.80 (4.10)	282 (230)	2.55 (5.00)	304 (208)	1.73 (3.77)
Swi Inc	608 (140)	9.18 (5.63)	634 (166)	9.80 (7.04)	620 (154)	9.38 (6.38)
Rep	467 (132)	4.37 (3.49)	456 (190)	4.60 (4.29)	459 (164)	4.36 (3.92)
Swi	468 (157)	5.16 (3.57)	471 (183)	6.09 (4.85)	466 (170)	5.36 (3.97)
Con	331 (175)	1.56 (2.87)	275 (227)	1.86 (3.28)	296 (203)	1.40 (2.49)
Inc	617 (132)	8.44 (5.43)	649 (169)	9.23 (7.24)	633 (152)	8.72 (6.40)
Total	469 (146)	4.83 (3.24)	470 (184)	5.46 (4.29)	467 (166)	4.93 (3.61)

All Cue-Stimulus Condition Together	Chinese (N = 16)		Non-Chinese (N = 16)		All Participants (N = 32)	
	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)
Rep Con	578 (255)	1.46 (2.45)	539 (287)	.92 (1.81)	558 (271)	1.20 (2.18)
Rep Inc	831 (233)	11.27 (7.49)	889 (280)	12.11 (8.53)	860 (258)	11.62 (7.80)
Swi Con	591 (251)	1.83 (3.10)	548 (294)	1.46 (3.00)	570 (273)	1.65 (3.04)
Swi Inc	829 (239)	11.99 (7.74)	884 (287)	12.68 (8.97)	856 (264)	12.34 (8.39)
Rep	702 (236)	6.50 (4.37)	706 (269)	6.42 (4.54)	704 (252)	6.64 (4.43)
Swi	703 (237)	6.88 (4.71)	713 (270)	7.19 (5.11)	708 (253)	7.04 (4.89)
Con	587 (250)	1.67 (2.37)	545 (290)	1.24 (2.07)	566 (270)	1.46 (2.22)
Inc	832 (235)	11.57 (6.83)	889 (280)	12.58 (8.53)	860 (259)	12.07 (7.71)
Total	704 (235)	6.68 (4.08)	713 (267)	6.96 (4.63)	780 (250)	6.82 (4.34)

Note. Rep = repeat; Swi = switch; Con = congruent; Inc = incongruent; Com = composite; C-first = cue-first; T-first = target-first.

(*Appendices continue*)

Appendix C

Experiment 2b: Mean (SD) of RT ms and ER % of Each Trial Condition and Cue-Stimulus Orders of Chinese Participants

	Composite		C-first		T-first	
	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)	RT ms Mean (*SD*)	ER % Mean (*SD*)
Rep Con	872 (133)	3.81 (3.13)	667 (151)	.60 (1.27)	469 (208)	2.26 (5.59)
Rep Inc	1,051 (157)	15.49 (8.82)	760 (146)	8.97 (4.69)	748 (144)	11.35 (6.38)
Swi Con	979 (147)	5.95 (5.89)	683 (169)	1.67 (3.51)	459 (195)	1.17 (2.26)
Swi Inc	1,147 (167)	12.66 (4.77)	818 (189)	11.09 (8.07)	741 (157)	10.08 (5.36)
Rep	959 (126)	9.96 (5.76)	705 (138)	4.71 (2.37)	613 (156)	7.21 (4.59)
Swi	1,061 (149)	9.26 (3.93)	747 (168)	6.44 (4.49)	604 (156)	5.61 (3.31)
Con	939 (128)	5.07 (4.19)	671 (153)	1.26 (2.36)	465 (196)	1.65 (2.90)
Inc	1,108 (156)	14.17 (5.73)	795 (154)	10.51 (6.52)	747 (146)	10.33 (5.21)
Total	1,021 (135)	9.62 (3.82)	730 (154)	5.85 (3.50)	609 (156)	6.21 (3.34)

Note. Rep = repeat; Swi = switch; Con = congruent; Inc = incongruent; C-first = cue-first; T-first = target-first. Due to data trimming as detailed in the main text, the number of observations in each condition was not equal. For example, participants might have more valid congruent switch trials than congruent repeat trials because they had made more mistakes in congruent repeat trials. As a result, the mean congruent RT may not equal to one half (congruent repeat + congruent switch).

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