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Testing theoretical assumptions underlying the relation between anxiety, mind wandering, and task-switching: A diffusion model analysis

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Testing Theoretical Assumptions Underlying the Relation Between Anxiety, Mind Wandering, and Task-Switching: A Diffusion Model Analysis [1]

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ABSTRACT

Despite the well-documented negative effects of anxiety on task-switching (switch costs), few studies have directly tested major theoretical assumptions about (a) the specific processing component of task-switching that is impaired by anxiety, (b) anxious individuals' strategies during task-switching, and (c) the mediating role of mind wandering in the relation between anxiety and task-switching. We addressed these issues using a stochastic diffusion model analysis and novel thought-probe technique in the task-switching paradigm. Our results suggest that the locus of impaired switch costs under state anxiety lies in the efficiency of task-set reconfiguration and not in proactive interference processing. Moreover, state anxiety was associated with impaired mixing costs, which are another crucial index of task-switching. We found only partial evidence for anxious individuals' proneness to compensatory strategies during task-switching. However, no evidence was found for a mediating role of task-unrelated thoughts and a moderating role of working memory in the relation between anxiety and task-switching. Our findings elucidate theoretical assumptions underlying anxiety and cognitive functioning.

KEYWORDS: anxiety, stochastic diffusion model, task-switching, switch costs, mixing costs

Research has suggested that anxiety is hugely disruptive to cognitive functioning, even when the task is not threatening (Edwards et al., 2015; Eysenck et al., 2007; Hartanto & Yang, 2016b). This is generally true for either trait anxiety, which refers to a stable individual's tendency to experience anxiety across various contexts, and state anxiety, which refers to an experience of apprehension in response to subjectively threatening events that have uncertain outcomes. In particular, studies that have examined the influence of anxiety on task-switching—the ability to switch back and forth between multiple tasks, operations, or mental sets (Monsell, 2003)—have reported that high levels of trait or state anxiety were associated with impaired task-switching performance when assessed in terms of response time (RT), but not accuracy (Ansari et al., 2008; Derakshan et al., 2009; Edwards et al., 2015).

To our best knowledge, however, no study has examined the specific processing components of switch costs (i.e., the transient costs of task-switching) that are disrupted by anxiety (Eysenck & Derakshan, 2011; Mayr & Kliegl, 2003; Ruthruff et al., 2001) or the relation between anxiety and mixing costs—another crucial index of task-switching, which captures global control processing in task-switching. More important, given that most empirical studies draw on attentional control theory (Eysenck et al., 2007), only a few studies have directly tested three theoretical assumptions: (a) the negative effect of anxiety on task-switching is because of impaired task-set configuration, (b) anxious individuals use compensatory strategies to maintain their task-switching accuracy, and (c) impaired task-switching efficiency is because of distracting threat stimuli, such as worrisome thoughts. Given these unresolved empirical and theoretical issues, we aimed to examine them using two methodological innovations: a novel thought-probe method (Stawarczyk et al., 2011; Unsworth & McMillan, 2014) and stochastic diffusion model analysis (Ratcliff, 1978).

Attentional Control Theory

Attentional control theory (Eysenck et al., 2007) has been widely used to explain why trait and state anxiety impair task-switching (for a theoretical review of the effect of anxiety on cognitive performance, see Derakshan & Eysenck, 2009). The theory postulates that both trait and state anxiety reduce attentional focus during task-switching because attentional resources are preferentially allocated to either internal threat-related stimuli (e.g., worrisome thoughts) or external threat-related stimuli (e.g., threatening task-irrelevant distractors). As a result, task-switching performance should be compromised because of the reduced attentional resources available for actual switching between two tasks. The theory makes three important assumptions that merit further investigation.

First, the theory assumes that anxiety likely entails compensatory strategies that result in a trade-off between effectiveness (accuracy) and efficiency (response time, RT; Eysenck et al., 2007).

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2007). Anxiety has been found to affect RT in task-switching, but not accuracy (Ansari et al., 2008; Derakshan et al., 2009; Edwards et al., 2015). The theory accounts for this finding by assuming that anxiety motivates individuals to adopt conservative decision styles to maintain performance effectiveness at the cost of efficiency, that is, increased processing time. Performance effectiveness concerns the quality of performance, which is typically assessed by outcome measures such as accuracy on the task, whereas processing efficiency concerns the investment in and operation of processing resources (e.g., time spent on the task), which is typically assessed by RT. However, although the negative effect of anxiety on RT (but not on accuracy) can be interpreted in favor of anxious individuals' use of compensatory strategies, this interpretation should be assessed with caution, because accuracy measures are potentially vulnerable to ceiling effects (Dixon, 2008) and are less reliable than RT measures in a task-switching paradigm (Hartanto et al., 2016). Moreover, individual differences in task-switching performance are typically observed in RTs rather than accuracy. For instance, the null effect on accuracy has been demonstrated in a wide range of research areas, including aging (Kramer et al., 1999; Kray et al., 2002); developmental disorders (Gargaro et al., 2015); positive emotion (Yang & Yang, 2014); and other experiential factors such as second language usage or video gaming (Green et al., 2012; Hartanto & Yang, 2019; Yang et al., 2018). In view of this, the lack of an effect of anxiety on accuracy may simply reflect an artifact in the measurement, instead of anxious individuals' use of compensatory strategies. Despite the empirical and theoretical importance of this phenomenon, by which trait and state anxiety impair RT but not accuracy (Ansari et al., 2008; Goodwin & Sher, 1992), few studies have directly tested the theoretical assumption that concerns the use of compensatory strategies under anxiety. Hence, more studies are warranted to verify anxious individuals' use of compensatory strategies in task-switching.

Second, attentional control theory assumes that the negative effect of trait and state anxiety on switch costs is because of impaired efficiency in task-set reconfiguration—that is, a controlled process of replacing a task with a new task (Rogers & Monsell, 1995). Although some previous findings of greater switch costs in individuals with high levels of either trait (Ansari et al., 2008) or state anxiety (Derakshan et al., 2009) appear to partially support this assumption, they are not entirely unequivocal in two respects. No studies have clearly found that both state and trait anxiety are associated with switch costs. For example, Derakshan et al. (2009) found that only state anxiety, not trait anxiety, was associated with switch costs. Moreover, given that switch costs arise not only from task-set reconfiguration, but also from proactive interference—that is, a general slowdown when switching to a new task because of interference from a previous task (Wylie & Allport, 2000)—previous studies have not investigated how anxiety would affect these different processing components of switch costs. Therefore, further studies are needed to test the theoretical assumption that anxiety impairs task-switching efficiency via its negative influence on task-set reconfiguration processing or proactive interference.

Lastly, attentional control theory posits that anxiety impairs task-switching efficiency, since attentional resources are devoted to either internal threat-related stimuli (e.g., worrisome thoughts) or external threat-related stimuli (e.g., threatening task-irrelevant distractors). In the absence of apparently threatening task-irrelevant distractors (e.g., threatening word distractors), however, the negative relation between anxiety and task-switching efficiency should be attributed to internal threat-related stimuli such as worrisome thoughts. However, there is little evidence that supports the mediating role of worrisome thoughts in the relation between anxiety and task-switching performance. Specifically, several studies that examined worrisome thoughts either before or after completion of the task (Forster et al., 2015; Harris, 2013; Moser et al., 2012) failed to find any significant relation between worries and cognitive performance, although the reliability of methods for quantifying worrisome thoughts, either prospectively or retrospectively, may be questionable (Nisbett & Wilson, 1977). Moreover, neuroimaging studies (Bishop, 2009; Forster et al., 2015) suggest that trait anxiety is associated with substantially reduced attentional control that is not necessarily caused by worrisome thoughts. For instance, Forster et al. (2015) argue that worrisome thoughts are generally the product of impoverished attentional control, which is evident under trait anxiety. In favor of this, the literature on mind wandering suggests that diminished attentional control increases mind wandering, but not vice versa (McVay & Kane, 2009, 2010). In view of these findings, examining the theorized mediating role of worrisome thoughts in the relation between anxiety and task-switching is an interesting next step.

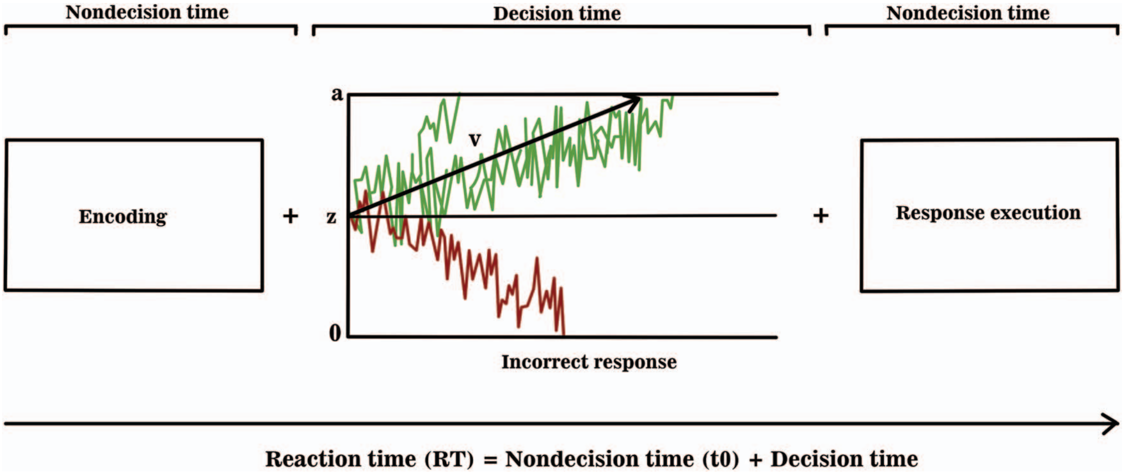
Research Goals

Our research goals were fivefold. First, we aimed to elucidate the specific processing component of task-switching that is affected by anxiety. To this end, we used stochastic diffusion model analysis (Ratcliff, 1978) to decompose switch costs into two processing components: task-set reconfiguration and proactive interferences. Based on the assumption that decisions are based on the accumulation of information over time until a response boundary is reached and a motor response elicited (see Figure 1), the diffusion model derives a number of meaningful parameters by using information provided by the positions, shapes, and sizes of empirical RT distributions. The parameters of our primary interest are drift rate (v), which quantifies the speed and direction of information accumulation during the decision process, and nondecision time ($t0$), which quantifies the duration of all nondecision processes, such as encoding or response execution. Recent studies that used a diffusion model (Karayanidis et al., 2009; Mansfield et al., 2011; Schmitz & Voss, 2012, 2014) have demonstrated that nondecision time ($t0$) captures an earlier phase of a task switch, which reflects task-set reconfiguration processing, while drift rate (v) captures a later phase of a task switch, which reflects proactive interference. Therefore, examining nondecision time ($t0$) and drift rate (v) of the diffusion model would allow us to examine whether impaired switch costs under anxiety can be attributed to either task-set reconfiguration or proactive interference. Drawing on attentional control theory (Eysenck et al., 2007), we hypothesized that if impaired switch costs under anxiety are because of task-set reconfiguration processing, both trait and state anxiety would impair nondecision time ($t0$) but not drift rate (v).

Second, we aimed to examine whether anxiety is prone to facilitating the use of compensatory strategies during task-switching. Given the theoretical assumption that anxious individuals are motivated to maintain their effectiveness (i.e., accuracy) in

Figure 1

Diffusion Processes Underlying the Diffusion Model



Note. The model assumes that decisions are based on information accumulation over time, which is represented by the drift rate (v) that begins at starting point (z) until a response boundary (0 or a) is reached and a motor response elicited. The entire process is assumed to be noisy and results in a different fluctuation per trial, even when identical information is available (Ratcliff, 1978; see Voss et al., 2013, for a practical introduction to diffusion models). From "A Diffusion Model Analysis of Developmental Changes in Children's Task Switching," by W. D. Weeda, M. W. van der Molen, F. Barceló, and M. Huizinga, 2014, *Journal of Experimental Child Psychology, 126*, p. 180. Copyright [2014] by Elsevier Inc. Reprinted with permission. See the online article for the color version of this figure.

task-switching at the expense of processing efficiency (i.e., slower processing time; Eysenck et al., 2007), anxious individuals' use of compensatory strategies during task-switching can be tested by another parameter of the diffusion model, boundary separation (a), which quantifies the speed–accuracy trade-off. A higher value of boundary separation reflects higher accuracy at the expense of slower RT (Starns & Ratcliff, 2010), which in turn indicates a conservative decision style that is consistent with the notion of a compensatory strategy. Given this, we hypothesized that if anxiety facilitates performance effectiveness (accuracy) at the cost of processing efficiency (RT) via the use of compensatory strategies during task-switching, higher state or trait anxiety should entail larger boundary separation values. Specifically, we hypothesized that anxiety would be positively associated with boundary separation when calculated in mixed blocks, which demand task-switching, but not in pure blocks, which do not. This would suggest that anxious individuals' conservative tendency is selective, depending on the rigor of the task—that is, their conservative tendency reflects their compensatory strategies for maintaining high accuracy during the task-switching that occurs only in mixed blocks. Furthermore, if compensatory strategies suppressed the negative effect of anxiety on performance effectiveness (accuracy), we expected that statistically controlling for compensatory strategies (indexed by boundary separation parameters) would result in impaired task-switching effectiveness.

Third, we aimed to examine the relation between anxiety and mixing costs—another critical index of task-switching performance in the paradigm. Research on anxiety and task-switching has mostly focused on switch costs (Ansari et al., 2008; Derakshan et al., 2009; Edwards et al., 2015), which implicate transient control processes at a local level that trigger switching from one task set to another (Monsell, 2003). However, task-switching entails not only switch costs, but also mixing costs that arise from global control mechanisms when monitoring and maintaining two competing task sets (Braver et al., 2003; Rubin & Meiran, 2005). Given that different control mechanisms underlie switch and mixing costs, a critical question is whether the adverse effect of anxiety on switch costs extends to mixing costs that are rooted in global control mechanisms and essential for facilitating task-switching by optimizing one's preparation to switch (Braver et al., 2003). As predicted by attentional control theory, we hypothesized that if anxiety impairs processing efficiency (RT) in task-switching, both state and trait anxiety would result in greater mixing costs.

Fourth, we aimed to examine the mediating role of task-unrelated thoughts (TUT) in the relation between anxiety and task-switching. To assess TUT without resorting to either prospective or retrospective measurements, we used an online thought probe technique (Stawarczyk et al., 2011; Unsworth & McMillan, 2014) during task-switching, in which participants were asked at random points to report whether their immediately preceding thoughts were on- or off-task. Despite the introspective nature of this technique, previous studies have demonstrated that an online thought-probe technique is reasonably valid for assessing TUT and predicts cognitive performance significantly better than other objective markers of mind wandering, such as intraindividual RT patterns (McVay & Kane, 2012). Moreover, to test the theory's prediction that anxiety would reduce attentional focus during task-switching by increasing threatening worrisome thoughts (especially in the absence of external threatening task-irrelevant distractors), we modified the thought-probe technique to differentiate between nonthreatening TUT (e.g., daydreaming) and threatening

TUT (e.g., worries), and hypothesized that the negative effect of anxiety on task-switching would be mediated by the frequency of threatening TUT, but not by nonthreatening TUT. However, if the frequency of threatening TUT does not mediate the effect of anxiety on task-switching, this would provide evidence in favor of the alternative view, which is based on recent neuroimaging findings (Forster et al., 2015) and suggests that impoverished prefrontal mechanisms under anxiety are not caused by worrisome thoughts, but rather reflect an inherent characteristic of trait anxiety.

Lastly, we aimed to explore the moderating effect of working memory capacity (WMC), which refers to the ability to maintain task-relevant information in the face of concurrent interference (Engle et al., 1999), on the relation between anxiety and task-switching. Although attentional control theory predicts that anxiety impairs processing efficiency (RT), some studies have failed to replicate this, even using similar tasks (e.g., Harris, 2013; Unsworth et al., 2009). Furthermore, Seipp's (1991) meta-analysis found that the negative correlation between anxiety and task performance was heterogeneous, given that some studies had reported null effects of anxiety or even a positive association between anxiety and performance. This inconsistency suggests the presence of exceptional cases, in which anxiety can be nonthreatening—or even beneficial—for processing efficiency. Our exploration of WMC as a potential moderator was motivated by recent studies that suggest that WMC minimizes the cognitive consequences of anxiety. For instance, Owens et al. (2014) found that WMC significantly moderated the relation between anxiety and mathematical performance. Specifically, anxiety and mathematical performance were positively correlated in participants with high WMC, but negatively correlated in those with low WMC. Similarly, Johnson and Gronlund (2009) found that trait anxiety did not affect high WMC individuals on a dual task, which consisted of a highly demanding memory task as a primary task and an auditory probe task as a secondary task. These findings suggest that individual differences in WMC may protect some from the negative impact of anxiety. Given this, we hypothesized that WMC would moderate the relation between anxiety and task-switching. In other words, anxiety would impair task-switching only in individuals with low WMC, but it would not impair (or alternatively, benefit) task-switching in those with high WMC.

Method

Participants

One hundred and 60 undergraduates (female = 119) from a local university participated in exchange for extra course credit. The sample size was determined a priori using G*Power (Faul et al., 2007) to ensure at least 95% power to detect a medium effect ($\rho = .3$; e.g., Ansari et al., 2008; Derakshan et al., 2009). Three participants were excluded because of technical errors during the study, and five participants who felt unwell or failed to follow instructions were also excluded. This resulted in a final sample of 152 participants (female = 113), with an average age of 20.9 years (*SD* = 1.74, range = 18–26). Participants were from varying socioeconomic status (SES) levels, as indexed by their monthly household income in Singapore dollars: less than S$2,500 (8.6%); S$2,500–S$4,999 (17.8%); S$5,000–S$7,499 (20.4%); S$7,500–S$9,999 (15.8%); S$10,000–S$12,499 (12.5%); S$12,500–S$14,999 (7.9%); S$15,000–S$17,499 (7.2%); S$17,500–S$19,999 (3.3%); or more than S$20,000 (6.6%). The study was approved by the Singapore Management University's Institutional Review Board, and informed consent was obtained from all participants before the study.

Materials

Task-Switching Paradigm With Thought Probing

A task-switching paradigm (Rubin & Meiran, 2005) was used to examine switch and mixing costs. Participants were asked to respond as fast and accurately as possible to either the color (red or green) or shape (circle or triangle) of a bivalent stimulus (i.e., red triangle and green circle), according to the cue presented. Participants responded by pressing either the left key, marked "red" and "circle," or the right key, marked "green" and "triangle," with the two keys counterbalanced across the participants.

Participants were instructed to complete one practice block comprising 30 trials and eight experimental blocks, in the following order: (a) two pure color and shape blocks, the order of which was counterbalanced across participants; (b) four mixed blocks; (c) two pure blocks. All blocks were presented in this fixed order. Pure blocks consisted of only one task cue and did not involve task-switching. Mixed blocks consisted of two task cues that required either task-repeating (repeat trials) or task-switching (switch trials) at unpredictable times. On repeat trials, the same task from a preceding trial was presented on a subsequent trial, whereas on switch trials, switching occurred from one task (e.g., color) to another (e.g., shape). Switch costs were calculated in mixed blocks by subtracting either mean RTs or accuracy on repeat trials from those on switch trials. Mixing costs were calculated by subtracting either mean RTs or accuracy on trials in pure blocks from those on repeat trials in mixed blocks (Rubin & Meiran, 2005).

Each pure block consisted of 40 trials and each mixed block of 80 trials. In the mixed blocks, half of the trials involved task-switching (switch trials) and the other half involved repeat trials; trials in the mixed blocks were randomly presented, with a maximum of four consecutive trials of the same task. Together, there were a total of 480 trials, with 160 trials per each trial type (i.e., pure, repeat, and switch trials). To increase the robustness of the diffusion model analysis and use the Kolmogorov–Smirnov statistic (Voss & Voss, 2007) as the optimization criterion, we determined the number of trials based on Voss et al.'s (2013) recommendation of more than 100 trials for each participant. A color gradient and a row of small black shapes were used as cues to indicate color and shape tasks, respectively. There were two possible targets (i.e., a red triangle or a green circle). For each trial, a fixation cross appeared for 350 ms and was followed by a blank screen for 150 ms. Subsequently, the cue appeared for 250 ms and was followed by the target.

To enhance the task's demand on proactive interference and task-set reconfiguration, we modified Rubin and Meiran's (2005) color-shape task in two notable respects. First, we adopted overlapping response mapping, in which two response keys were assigned to four attributes of two bivalent target stimuli (a green circle and red triangle), with each response key mapped to two attributes, that is, a left response key for red and circle and a right key for green and triangle; note that the target stimulus did not match a response key on both color and shape. For instance, for the target stimulus of a green circle, participants should press a left response key if the cue is shape (“circle”) and a right key if the cue is color (“green”). This setup differed from Rubin and Meiran’s (2005) switching task with nonoverlapping response mapping, which allowed four response keys, with each response key mapped to only one attribute out of the four possible. Previous studies have found that overlapping response mapping increases task demand on the proactive interference and task-set reconfiguration that underlie switch costs (Gade & Koch, 2007; Meiran, 2000, 2008). The second modification was the use of stimulus-response incompatibility. That is, the target stimulus did not match a response key on both color and shape; thus, a correct answer for the shape task is always wrong for the color task, and vice versa. Consequently, this modification required task-inertia and response recoding, which would impose greater demand on task-set reconfiguration and proactive interference; thereby, rendering the task more sensitive for detecting individual differences in switch and mixing costs (e.g., Hartanto et al., 2016; Hartanto & Yang, 2016b).

During the task, participants were also periodically probed and prompted to press one of seven keys to indicate what they were thinking immediately before the presentation of the probe (Stawarczyk et al., 2011; Unsworth & McMillan, 2014). Thought-probing questions were as follows: (a) *I am totally focused on the current task*; (b) *I am thinking about my performance on the task or how long it is taking*; (c) *I am thinking about some of my concerns, troubles, or fears*; (d) *I am thinking some important stuff or recent worries*; (e) *I am distracted by information present in the room (sights or sounds)*; (f) *I am having some fantasies that are disconnected from reality*; and (g) *I am thinking some unimportant stuff*. Of these seven choices, the first was coded as an on-task thought and the second as task-related interference (TRI). We distinguished on-task thoughts from TRI, because the latter was regarded as a form of lapsed attention and indicated that the participant was not fully focused on the task (Smallwood et al., 2004). We coded the third and fourth choices as threatening TUT, the fifth as external distraction, and the sixth and seventh as nonthreatening TUT.

Several steps were taken to minimize the likelihood that our thought-probe technique might influence the validity of our switch costs. First, to minimize the possibility of thought-probe questions’ interfering with task-switching performance, we embedded them only after the participant had submitted their response on each trial. Thus, the occurrence of the thought probe should not directly disrupt participants’ task-switching performance. Second, thought-probe questions randomly appeared in 15% of the trials and equally frequently for both repeat and switch trials across all blocks. Accordingly, thought-probe questions were infrequent and, thus, less likely to exert systematic influence on the main task. Lastly, in our final analysis, we excluded trials with thought-probe questions. Thus, any potential noise driven by thought-probe questions was eliminated. Taken together, in view of the proven validity and prevalent use of the technique (Stawarczyk et al., 2011; Unsworth & McMillan, 2014), it is less likely that inclusion of the thought probe significantly influenced task-switching performance, at least in our study.

Complex Span Tasks

To obtain converging evidence, we used the rotation-span and symmetry-span tasks to measure WMC (Foster et al., 2015). We chose these tasks because they have been found to predict significantly more variance in working memory and fluid intelligence than other complex span tasks, such as the operation span. In the rotation-span task, participants were presented with a series of either short or long arrows pointing in one of eight directions and asked to remember both the arrow’s length and direction. After (or before) each of the arrows, participants were given a distractor in which they decided whether a rotated letter mirrored the target letter. Set size, which refers to the total number of arrows (length and direction) participants were asked to recall, varied from two to five per trial. Similarly, in the symmetry-span task, participants were instructed to judge whether a displayed shape was symmetrical along its vertical axis—that served to distract participants from processing a subsequent task—and then directed to remember the location of a red square that randomly appeared in a 4 × 4 grid. Set size—that is, the total number of locations of the red square—varied from two to five per trial. Each working memory task had two blocks, because it has been shown that the variance explained by a working memory task tends to plateau after two blocks. Scores in each task were computed using the partial-credit unit (PCU) method, in which the participant’s score was expressed as the proportion of the total number of correct recall responses in a set (Conway et al., 2005). PCU scores from the rotation-span and symmetry-span tasks were summed to compute each participant’s WMC (refer to Table A1 of Appendix for zero-order correlations among the cognitive variables).

State–Trait Anxiety Inventory (STAI)

State and trait versions of the STAI (Spielberg et al., 1983) were used to assess participants’ state and trait anxiety. The scale contained 20 items to measure state anxiety ($\alpha = .90$) and another 20 to measure trait anxiety ($\alpha = .90$) on a 4-point Likert scale. Participants’ responses were scored and summed to compute their state and trait anxiety.

Procedure

Participants were seated individually in an open cubicle and asked to sign an informed consent form. Subsequently, they were asked to complete the state version of the STAI before proceeding to the switching task with thought probing. Upon completion, participants were instructed to complete the rotation- and symmetry-span tasks. Finally, participants completed a demographic survey and the trait version of the STAI. The entire task took approximately 70 min to complete.

Results

Switch Costs in Accuracy, Binning Scores, and RT

Ordinary least squares (OLS) regression analyses were conducted to assess the predictability of state and trait anxiety in the effectiveness (accuracy and binning scores) and efficiency (RT) of switch costs in task-switching. For the analysis of RT, accurate responses that were either 2.5 *SD* above or below an individual's mean RT were excluded separately for pure and mixed blocks (see Table 1 for descriptive statistics). The effectiveness of switch costs was operationalized by using both accuracy (the percentage of accurate responses) and binning scores generated by a rank-ordered binning procedure that combined speed and accuracy data to form a single, comprehensive index of task-switching performance (see Draheim et al., 2016, for more details on calculating switch costs based on the binning procedure; Hughes et al., 2014).

Following the recommendation of Draheim et al. (2016), we calculated binning scores in several steps. First, we calculated the mean RT of correct repeat trials for each participant, then subtracted each participant's mean RT of correct repeat trials from the RT of each correct switch trial. The resulting RT differences were assigned to every accurate switch trial; we referred to these RT differences as trial-based switch costs. After this, each participant's trial-based switch costs were rank ordered into deciles and a bin value ranging from 1 to 10 was assigned to them. Greater bin values were assigned to trials with relatively larger switch costs (lower switching efficiency), whereas smaller bin values were assigned to trials with relatively smaller switch costs (higher switch efficiency). More important, to impose a stronger penalty for errors, the highest bin value of 20 was assigned to each inaccurate response (Hughes et al., 2014). That is, participants with more inaccurate responses ended up with higher bin values. Lastly, we averaged all of the bin values each participant received to create a single switch cost in binning scores, which ranged from 1 to 20. Together, by doubling the bin value (i.e., 20) for incorrect trials, compared with the bin value of 10 assigned to correct trials with the slowest RTs, binning scores can serve as a good proxy for performance effectiveness (accuracy) and demonstrate higher reliability than typical switch costs in accuracy (Draheim et al., 2016; Hughes et al., 2014).

We found that state anxiety did not significantly predict switch costs in RT ($B = 1.94$, $SE = 1.04$, 95% confidence interval, CI [−0.12, 4.00], $\beta = .15$, $t = 1.87$, $p = .064$); switch costs in accuracy ($B = 0.00$, $SE = 0.00$, 95% CI [0.00, 0.00], $\beta = -.06$, $t = -0.75$, $p = .453$); or switch costs in binning scores ($B = 0.02$, $SE = 0.01$, 95% CI [−.005, .046], $\beta = .13$, $t = 1.59$, $p = .114$). Similarly, trait anxiety also did not significantly predict switch costs in RT ($B = 1.66$, $SE = 1.00$, 95% CI [−0.30, 3.63], $\beta = .14$, $t = 1.67$, $p = .097$); switch costs in accuracy ($B = 0.00$, $SE = 0.00$, 95% CI [−0.00, 0.00], $\beta = .04$, $t = 0.51$, $p = .608$); or switch costs in binning scores ($B = 0.01$, $SE = 0.01$, 95% CI [−.018, .032], $\beta = .05$, $t = 0.57$, $p = .571$).

Diffusion Model Analysis of Switch Costs

We performed diffusion model analysis to decompose switch costs into task-set reconfiguration and proactive interference. In our computation, drift rate (v), nondecision time ($t0$), and boundary separation (a) were allowed to vary freely across pure, repeat, and switch trials. Following the recommendation of Voss et al. (2013), the starting point (zr) was fixed at the midpoint between the two response boundaries (i.e., 0 or a; $zr = 0.5$; see Figure 1). Similarly, the intertrial variability of diffusion model parameters and response-execution differences (d) were fixed to zero, except for the intertrial variability of nondecisional components ($st0$), which were held constant across trials (Hartanto & Yang, 2016a; Voss et al., 2013). Parameters were estimated using *fast-dm* for each participant, using the Kolmogorov–Smirnov (KS) test statistic for optimization of parameters (Voss et al., 2015). To examine model fit, we computed predicted (parameter-based) and empirical cumulative distribution functions (cdfs) for both switch and repeat trials for each participant based on the recommendation of Schmitz and Voss (2012) and Voss et al. (2013). As shown in Figure 2, we found good model fit, because most of the predicted cdfs fell on the empirical cdf line, supporting the validity of our diffusion

Table 1

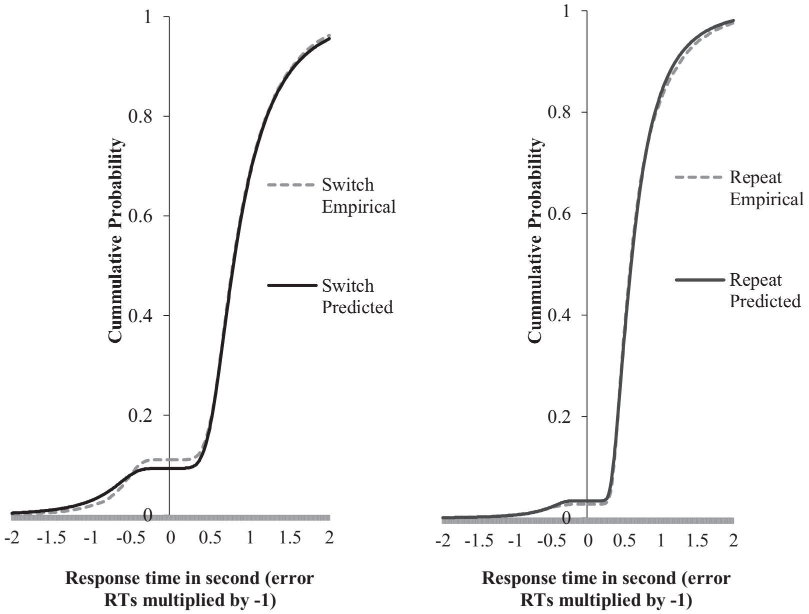
Descriptive Statistics of Anxiety, Task-Switching, and Working Memory Measures

Variable	*M*	*SD*	Range	Skewness	Kurtosis
Anxiety (STAI)					
State	40.04	8.77	23.00–69.00	0.64	0.85
Trait	46.70	9.19	27.00–71.00	0.14	−0.59
Boundary separation (a)					
Pure trials	1.26	0.31	0.50–2.38	0.65	0.72
Repeat trials	1.90	0.44	0.80–2.87	0.12	−0.41
Switch trials	1.80	0.44	0.83–2.94	0.47	−0.22
Switch costs					
Accuracy (%)	−0.08	0.05	−0.25–−0.03	−0.94	0.72
RT (ms)	234	113	−22–620	0.73	0.90
Binning score	7.12	1.41	3.95–11.53	0.68	0.61
Drift rate (v)	−0.60	0.53	−2.94–0.90	−1.35	4.08
Nondecision time ($t0$; ms)	148	105	−78–520	0.80	1.03
Mixing costs					
Accuracy (%)	−0.01	0.04	−0.19–0.22	0.08	11.31
RT (ms)	311	162	3–935	0.93	1.20
Working memory					
Rotation-span[a]	5.72	1.39	0.53–8.25	−1.00	1.36
Symmetry-span[a]	6.21	1.27	1.73–8.00	−1.30	2.16
Total score[b]	11.94	2.22	3.73–15.45	−1.24	1.93

Note. STAI = State–Trait Anxiety Inventory; RT = response time.
[a] Data from one participant were missing. [b] Data from two participants were missing.

Figure 2

Predicted (Parameter-Based) and Empirical Cumulative Distribution Functions (cdfs) for Both Switch and Repeat Trials Were Overlaid in the Two Graphs



Note. Following the suggestion of Schmitz and Voss (2012), predicted and empirical cdfs were first computed for each participant and then averaged across participants. Correct and incorrect cdfs are combined, with latencies of correct responses plotted on the right *x*-axis (with positive values) and latencies of incorrect responses plotted on the left *x*-axis (with negative values). The intercept of the cdf reflects the percentage of inaccurate responses. A perfect fit would be obtained if the predicted cdf falls on the empirical cdf line (Voss et al., 2013).

model analyses. We calculated switch costs in terms of drift rate—that captures proactive interference processes—by subtracting drift values on repeat trials from those on switch trials. Likewise, switch costs in terms of nondecison time—that captures task-set reconfiguration processes—were calculated by subtracting nondecision time on repeat trials from that on switch trials.

Similar to the analyses performed above for accuracy, binning scores, and RT data, a new set of regression analyses was conducted to elucidate the specific component of task-switching that is affected by state and trait anxiety. As shown in Figure 3, we found that state anxiety significantly predicted switch costs when calculated in terms of nondecision time ($B = 2.18$, $SE = 0.96$, 95% CI [0.29, 4.08], $\beta = .18$, $t = 2.27$, $p = .024$), but failed to predict switch costs in terms of drift rate ($B = 0.01$, $SE = 0.01$, 95% CI [-0.00, 0.02], $\beta = .16$, $t = 1.96$, $p = .052$). In contrast, trait anxiety failed to predict switch costs in terms of both nondecision time ($B = 1.52$, $SE = 0.92$, 95% CI [-0.31, 3.34], $\beta = .13$, $t = 1.64$, $p = .102$) and drift rate ($B = 0.01$, $SE = 0.01$, 95% CI [-0.02, 0.17], $\beta = .13$, $t = 1.56$, $p = .122$). These findings suggest that the negative relation between state anxiety and switch costs can be attributed to impaired task-set reconfiguration during task-switching.

Mixing Costs

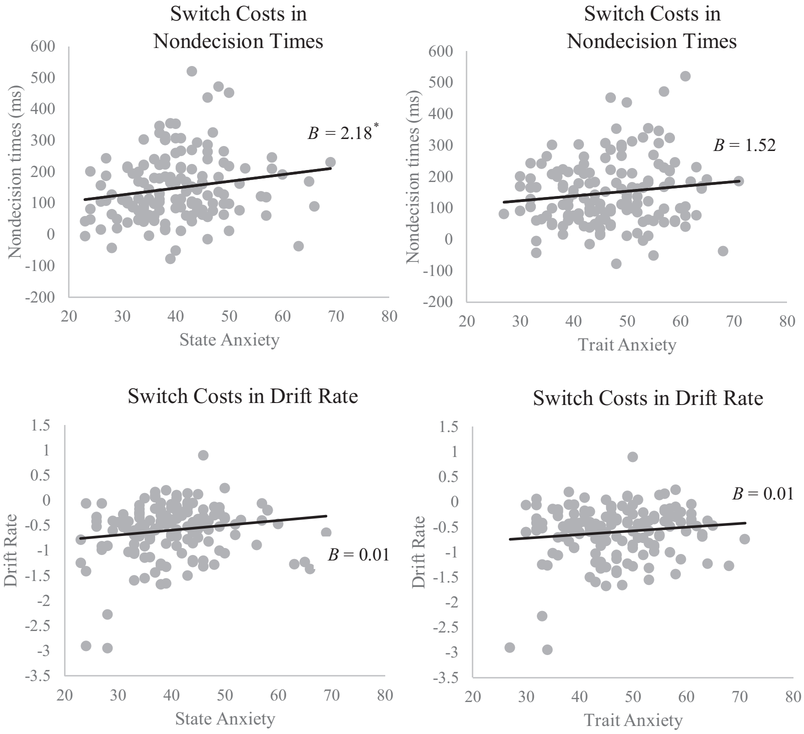
We conducted regression analyses to investigate whether state and trait anxiety predict mixing costs in terms of effectiveness (accuracy) or efficiency (RT). Similar to the analyses performed above for switch costs, accurate responses that were either 2.5 *SD* above or below an individual's mean RT were excluded separately for pure and mixed blocks. As shown in Figure 4, we found that state anxiety was a significant predictor of mixing costs in RT ($B = 3.76$, $SE = 1.48$, 95% CI [0.84, 6.68], $\beta = .20$, $t = 2.55$, $p = .012$), but not in accuracy ($B = 0.00$, $SE = 0.00$, 95% CI [-0.001, 0.001], $\beta = -.03$, $t = -0.38$, $p = .701$). However, we found that trait anxiety did not significantly predict mixing costs in either RT ($B = 1.86$, $SE = 1.43$, 95% CI [-0.97, 4.69], $\beta = .11$, $t = 1.30$, $p = .196$) or accuracy ($B = 0.00$, $SE = 0.00$, 95% CI [-0.001, 0.00], $\beta = -.04$, $t = 0.54$, $p = .592$). These results suggest that only state anxiety was associated with impaired efficiency of mixing costs (in RT).

Compensatory Strategies

To examine anxious individuals' proneness to adopt compensatory strategies during task-switching, we performed regression analyses to examine whether state and trait anxiety predicts boundary separation (*a*) of the diffusion model. We found that state anxiety emerged as a significant predictor of boundary separation for repeat trials ($B = 0.011$, $SE = 0.004$, 95% CI [0.003, 0.019], $\beta = .22$, $t = 2.81$, $p = .006$) and switch trials ($B = 0.009$, $SE = 0.004$, 95% CI [0.001, 0.017], $\beta = .18$, $t = 2.19$, $p = .030$), but not for pure trials ($B = 0.004$, $SE = 0.003$, 95% CI [-0.002, 0.009], $\beta = .10$, $t = 1.28$, $p = .202$). Similarly, trait anxiety significantly

Figure 3

Scatterplots and Regression Lines Indicating the Relation Between Anxiety and Switch Costs in Terms of Nondecision Time (Top Panel) and Drift Rate (Bottom Panel)



* $p < .05$.

predicted boundary separation for repeat trials ($B = 0.008$, $SE = 0.004$, 95% CI [0.000, 0.015], $\beta = .16$, $t = 2.00$, $p = .047$) and switch trials ($B = 0.008$, $SE = 0.004$, 95% CI [0.000, 0.015], $\beta = .16$, $t = 1.98$, $p = .049$), but not for pure trials ($B = 0.003$, $SE = 0.003$, 95% CI [-0.003, 0.008], $\beta = .07$, $t = 0.91$, $p = .367$). However, the relation between state anxiety and boundary separation for trials in pure blocks was not significantly different from the two relations state anxiety had with boundary separation for repeat trials ($z = 1.60$, $p = .059$) and switch trials ($z = 0.85$, $p = .197$) in mixed blocks. Similarly, the relation between trait anxiety and boundary separation for pure trials was not significantly different from the relation trait anxiety had with boundary separation for repeat ($z = 1.12$, $p = .131$) and switch trials ($z = 1.02$, $p = .155$). These findings suggest that individuals with greater state or trait anxiety behave conservatively in general and not selectively depending on task demands. They do this by using strategies (e.g., heightened cautiousness or intolerance of uncertainty) that enhance their performance effectiveness (accuracy) by sacrificing processing efficiency (see Figure 5).

Furthermore, we conducted hierarchical regression analyses to examine whether the use of a compensatory strategy could have suppressed potentially negative impacts of anxiety on task-switching effectiveness (accuracy), as predicted by attentional control theory. That is, we examined whether our null finding of anxiety on switch costs in accuracy could have occurred because of the use of compensatory strategies. To investigate this theoretical assumption, we tested our hierarchical regression model by entering anxiety in Step 1 of the model to predict task-switching effectiveness (i.e., switch costs in terms of accuracy or binning scores). In Step 2, we included boundary separation parameters—that were calculated for both repeat and switch trials—to estimate the unique effect of anxiety on performance effectiveness without the influence of compensatory strategies. We tested a separate model for state and trait anxiety.

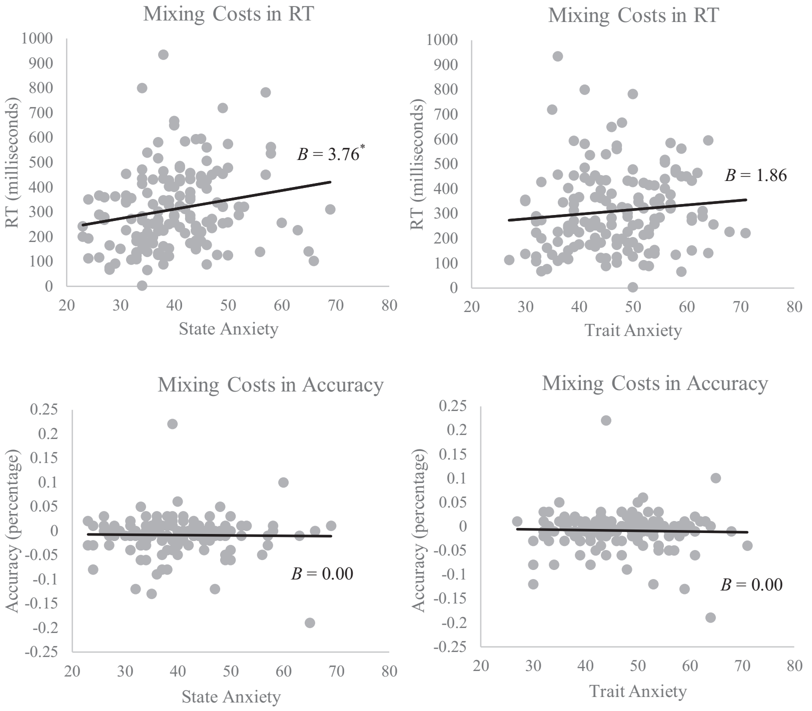
As shown in Table 2, state anxiety did not significantly predict switch costs in accuracy ($p = .453$) or those calculated by the binning procedure ($p = .114$). However, when boundary separations for repeat and switch trials—that indicate compensatory strategies—were controlled for in Step 2 of the model, state anxiety significantly predicted switch costs calculated by the binning procedure ($p = .002$) but not accuracy ($p = .063$). Taken together, we found only partial evidence that the use of compensatory strategies suppresses the negative influence of state anxiety on performance effectiveness in task-switching. However, there was no clear evidence that compensatory strategies suppress the potentially negative influence of trait anxiety on performance effectiveness.

Task-Unrelated Thoughts (TUT)

We conducted mediation analyses to examine whether threatening or nonthreatening TUT would mediate the relation between

Figure 4

Scatterplots and Regression Lines Indicating the Relation Between Anxiety and Mixing Costs in Terms of Response Time (RT; Top Panel) and Accuracy (Bottom Panel)



* $p < .05$.

anxiety and task-switching. We focused only on state anxiety as our independent variable, because trait anxiety failed to predict most of our criterion variables. We considered three potential mediators: (a) threatening TUT, (b) nonthreatening TUT, and (c) total TUT (threatening TUT + nonthreatening TUT; see Table 3 for the proportion of each thought type during the task). We included criterion variables that were found to be significantly associated with state anxiety: switch costs calculated in nondecision time ($t0$), mixing costs in RT, and boundary separations (a) for repeat trials and switch trials. Multiple mediation models were estimated using the PROCESS macro (Hayes, 2009), with bias-corrected bootstrapping of 10,000 samples for all analyses. Mediation was considered significant if 95% bias-corrected confidence intervals for indirect effects did not encompass zero (Preacher & Hayes, 2004).

As presented in Table 4, state anxiety was positively associated with threatening TUT and total TUT. However, threatening TUT and total TUT did not significantly predict any of our criterion variables (e.g., switch costs in nondecision time and mixing costs in RT). As a result, no indirect effects were significant across the 12 mediation models. This suggests that TUT does not mediate the negative effect of state anxiety on task-switching performance.

Working Memory Capacity (WMC)

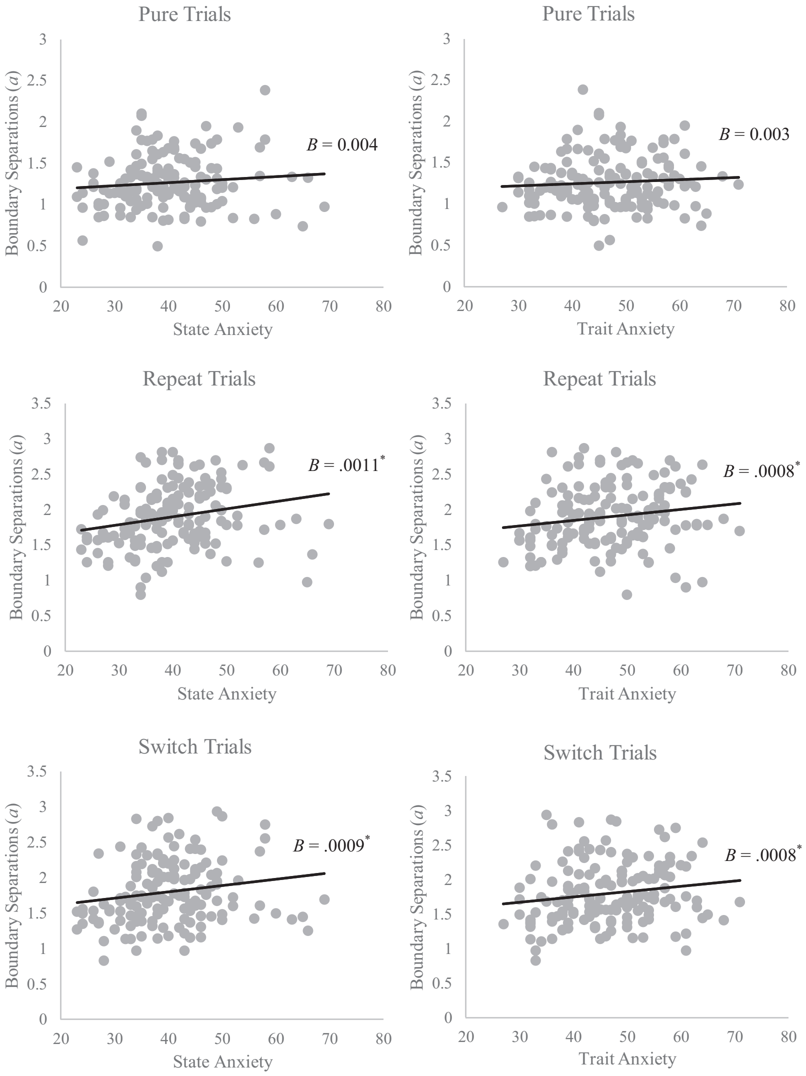
We performed a series of moderation analyses using the PROCESS macro (Model 1; Hayes, 2009) to examine whether WMC would moderate the effect of state or trait anxiety on task-switching performance. Because of a technical issue, data from one participant's rotation-span and symmetry-span tasks were excluded from the analyses. As shown in Table 5, interaction terms between anxiety and WMC did not significantly predict any indexes of task-switching performance. We also conducted Bayesian regression using JASP (JASP Team, 2018) to find evidence for a null effect. Based on the recommendation of Wagenmakers et al. (2018), in all of our Bayesian moderation analyses, we estimated the Bayes factor in favor of the model with two main effects over the one with an additional interaction (i.e., the interaction model). As shown in Table 6, our Bayesian analysis indicated anecdotal to moderate evidence in favor of the null effect of the moderating role of WMC on the relation between anxiety and our focal variables in task-switching. Taken together, these results indicate that WMC does not moderate the link between anxiety and task-switching.

Exploratory Analyses of the Interaction Between State and Trait Anxiety

We explored the interaction effects of state and trait anxiety on all of our outcome variables. As shown in Table 7, we found significant interaction effects of state and trait anxiety on switch costs in accuracy and drift rate, mixing costs in RT, boundary separation for pure trials, repeat trials, and switch trials. We conducted simple slope analyses to probe these interaction effects further. As shown in Figure 6, we found that state anxiety signif-

Figure 5

Scatterplots and Regression Lines Illustrating the Relation Between Anxiety and Boundary Separation (a) of the Diffusion Model—That Captures the Use of Compensatory Strategies—Across Different Types of Trials



* $p < .05$.

icantly predicted switch costs in drift rate, mixing costs in RT, and boundary separation for pure trials, repeat trials, and switch trial—except for switch costs in accuracy—in participants with lower trait anxiety, but not higher trait anxiety. Nevertheless, caution is necessary in interpreting these results because of the exploratory nature of moderation analyses and a high correlation between state and trait anxiety, $r = .545$, $p < .001$, which consequently partials out much of their construct-relevant variance in the moderation analyses.

Discussion

Our main findings contribute in many ways to clarifying both the empirical and theoretical underpinnings of the relation between anxiety and task-switching (switch and mixing costs). Below, we discuss the study's notable findings and their theoretical implications in more detail.

First, given that switch costs implicate (a) task-set reconfiguration in alternating between two task sets and (b) proactive interference from the previous task set, our study elucidates the specific processing component of switch costs that is influenced by anxiety. Drawing on two diffusion-model parameters of nondecision time ($t0$) and drift rate (v) that primarily reflect task-set reconfiguration and proactive interference processes, respectively (Schmitz & Voss, 2012, 2014), we found that state anxiety was associated with higher values of nondecision time for switch costs, but not with drift rate. These results suggest that state anxiety influences

Table 2

Summary of Hierarchical Multiple Regression Analyses for Predicting Switch Costs Calculated in Accuracy and by the Binning Procedure

Variable	Step 1			Step 2		
	B (*SE*)	β	*p*	*B* (*SE*)	β	*p*
Model 1: DV = Switch costs (accuracy)						
State anxiety	0.000 (.000)	−.061	.453	−0.001 (.000)	−.145	.063
Boundary separation (repeat trials)	—	—	—	0.025 (.014)	−.204	.061
Boundary separation (switch trials)	—	—	—	0.025 (.014)	−.219	.083
Model 2: DV = Switch costs (binning score)						
State anxiety	0.021 (.013)	.129	.114	0.037 (.012)	.229	.002
Boundary separation (repeat trials)	—	—	—	−1.677 (.362)	−.523	.000
Boundary separation (switch trials)	—	—	—	0.301 (.356)	.094	.399
Model 3: DV = Switch costs (accuracy)						
Trait anxiety	0.000 (.000)	.042	.514	0.000 (.000)	−.021	.786
Boundary separation (repeat trials)	—	—	—	0.021 (.014)	.175	.138
Boundary separation (switch trials)	—	—	—	0.026 (.014)	.218	.065
Model 4: DV = Switch costs (binning score)						
Trait anxiety	0.007 (.012)	.046	.571	0.017 (.012)	.110	.148
Boundary separation (repeat trials)	—	—	—	−1.555 (.367)	−.484	.000
Boundary separation (switch trials)	—	—	—	0.282 (.365)	.088	.441

Note. DV = dependent variable. Higher *B* values reflect better performance in switch costs in accuracy, while lower *B* values reflect better performance (i.e., smaller bin values) in switch costs calculated by the binning procedure.

switch costs via task-set reconfiguration and not via proactive interference. Our findings support the prediction of the attentional control theory (Eysenck et al., 2007) that the adverse effect of anxiety on switch costs is caused by impaired efficiency during the task-set reconfiguration process, which requires top-down attentional control. Given that task-set reconfiguration is considered to be an essential aspect of the control mechanism of executive functions (Meiran, 1996; Rogers & Monsell, 1995), which are the higher-order cognitive processes that regulate goal-directed actions (Miyake et al., 2000), our findings are consistent with previous studies that report negative effects of anxiety on the processing efficiency of other core executive functions, such as inhibitory control (e.g., Ansari & Derakshan, 2010).

On the other hand, however, our finding of the absence of a relation between trait anxiety and switch costs contradicts previous findings of significant associations between trait anxiety and switch costs (Derakshan et al., 2009; Edwards et al., 2015). This inconsistency may be because of trait anxiety's more subtle impairment of task-switching than state anxiety, as the former is assumed to be a predisposition to experience state anxiety (Eysenck et al., 2007; see Booth & Peker, 2017, for similar findings). This explanation is in line with the notion that state anxiety is more crucial than trait anxiety in determining individual differences in processing efficiency and performance effectiveness (Eysenck & Calvo, 1992, p. 414). Alternatively, our discrepant results could be simply because of measurement-related (e.g., STAI) or task-specific issues.

Moreover, our finding that impaired processing efficiency in switch and mixing costs is more directly related to state anxiety than trait anxiety is not consistent with behavioral (Pacheco-Unguetti et al., 2010) and neuroimaging (Bishop et al., 2009; Forster et al., 2015) studies, which suggest that high trait anxiety is associated with impoverished attentional control on behavioral tasks and the prefrontal mechanism underlying attentional functioning, respectively. Those studies claim that anxiety-related deficits in prefrontal functioning might reflect an underlying characteristic of trait anxiety, and do not necessarily arise from state anxiety or worrisome thoughts (i.e., TUT). Given this discrepancy, more research is warranted to examine the causal relation between state and trait anxiety, TUT, and impaired recruitment of prefrontal mechanisms.

The second notable finding is that our study extends the understanding of the cognitive effects of anxiety on the mixing costs of task-switching. The majority of previous studies have focused on switch costs (Derakshan et al., 2009; Edwards et al., 2015), and little is known about the impact of anxiety on mixing costs. Yet, the latter implicates global sustained control mechanisms in monitoring and maintaining two competing task sets and resolving the interference or conflicts that arise from them (Rubin & Meiran, 2005). Although processing efficiency in maintaining two com-

Table 3

Proportions of Each Thought Type During Task-Switching in Pure and Mixed Blocks

Type of block	On-task	TRI	Threatening TUT	Nonthreatening TUT	ED
Total	0.55 (0.31)	0.28 (0.25)	0.08 (0.17)	0.07 (0.12)	0.03 (0.06)
Pure blocks	0.62 (0.33)	0.23 (0.26)	0.07 (0.18)	0.06 (0.11)	0.03 (0.06)
Mixed blocks	0.51 (0.34)	0.30 (0.28)	0.08 (0.18)	0.07 (0.14)	0.04 (0.07)

Note. TRI = task-related interference; ED = external distraction. *SD*s are shown in parentheses.

Table 4

Summary of Mediation Analyses With State Anxiety as an Independent Variable

Mediator (M)	Dependent variable (DV)	Effect of IV on M (*a*)	Effect of M on DV (*b*)	Total effect (*c*)	Direct effect (*c'*)	Indirect effect	95% CI for indirect effect	κ^2
Threatening TUT	Switch costs ($t0$)	0.007 (0.002)**	−56.04 (51.68)	2.18 (0.96)*	2.57 (1.02)*	−0.39 (0.36)	[−1.347, 0.085]	0.03
	Mixing costs (RT)	0.007 (0.002)**	69.92 (79.61)	3.76 (1.48)*	3.28 (1.58)*	0.48 (0.69)	[−0.940, 1.888]	0.03
	BS for repeat trials	0.007 (0.002)**	0.08 (0.22)	0.01 (0.00)*	0.01 (0.00)*	0.00 (0.00)	[−0.004, 0.003]	0.01
	BS for switch trials	0.007 (0.002)**	−0.02 (0.22)	0.01 (0.00)*	0.01 (0.00)*	0.00 (0.00)	[−0.005, 0.003]	0.03
Nonthreatening-TUT	Switch costs ($t0$)	0.002 (0.001)	99.99 (71.63)	2.18 (0.96)*	2.02 (0.96)*	0.16 (0.22)	[−0.107, 0.826]	0.01
	Mixing costs (RT)	0.002 (0.001)	103.06 (110.56)	3.76 (1.48)*	3.60 (1.49)*	0.16 (0.26)	[−0.120, 0.893]	0.01
	BS for repeat trials	0.002 (0.001)	0.45 (0.30)	0.01 (0.00)*	0.01 (0.00)*	0.00 (0.00)	[−0.000, 0.003]	0.01
	BS for switch trials	0.002 (0.001)	0.35 (0.30)	0.01 (0.00)*	0.01 (0.00)*	0.00 (0.00)	[−0.000, 0.003]	0.01
Total TUT	Switch costs ($t0$)	0.009 (0.002)**	−3.06 (44.09)	2.18 (0.96)*	2.21 (1.03)*	−0.03 (0.45)	[−1.016, 0.783]	0.00
	Mixing costs (RT)	0.009 (0.002)**	89.04 (67.42)	3.76 (1.48)*	3.00 (1.58)	0.76 (0.61)	[−0.399, 2.026]	0.04
	BS for repeat trials	0.009 (0.002)**	0.22 (0.18)	0.01 (0.00)*	0.01 (0.00)*	0.00 (0.00)	[−0.001, 0.005]	0.04
	BS for switch trials	0.009 (0.002)**	0.11 (0.19)	0.01 (0.00)*	0.01 (0.00)*	0.00 (0.00)	[−0.003, 0.005]	0.02

Note. CI = confidence interval. *SE*s are shown in parentheses. State anxiety was used as an independent variable in all analyses. Analyses were conducted with bias-corrected bootstrapping with 10,000 samples. TUT = task-unrelated thought; switch costs ($t0$) = nondecision times of switch costs in response time (RT); mixing costs (RT) = mixing costs in RT; BS = boundary separations.

* $p < .05$. ** $p < .001$.

peting task sets has been deemed essential for successful task-switching, because it optimizes one's preparation to switch (Braver et al., 2003), our study is the first to investigate the potential impact of anxiety on mixing costs. Hence, our finding of positive associations between state anxiety and mixing costs in RT (but not in accuracy) extends the literature by demonstrating that anxiety impairs not only switch costs but also mixing costs.

Third, we only found partial evidence for the use of compensatory strategies by anxious individuals. Attentional control theory predicts that anxious individuals are motivated to protect their performance effectiveness (accuracy) from the adverse effects of anxiety by sacrificing processing efficiency (RT) in task-switching. We examined this theoretical prediction by computing boundary separation parameters of the diffusion model, which quantify conservative decision styles. We found that both state and trait anxiety were positively associated only with boundary separations of mixed blocks and not those of pure blocks. However, the relation between anxiety and boundary separation in mixed blocks was not significantly different from that between anxiety and boundary separation in pure blocks. Moreover, we found only one significantly suppressing role of the compensatory strategy—out of four analyses—in the relation between state anxiety and switch costs in binning scores. These findings suggest that there is no strong evidence that anxious individuals selectively enhance performance effectiveness by sacrificing processing efficiency, especially when tasks are demanding and require extra attentional control in switching from one task to another (as in mixed blocks). In fact, it is plausible that the positive correlation between anxiety and boundary separation is because of an overall heightened level of cautiousness or higher intolerance of anxiety, instead of engagement in compensatory strategies. Nevertheless, the finding should be carefully interpreted because many factors, such as task instruc-

Table 5

Summary of Interactions Between Anxiety and WMC on Task-Switching Using Ordinary Least Squares Regression

Interaction	DV	*B*	*SE*	95% CI	*p*
State Anxiety × WMC	Switch costs (RT)	−0.069	0.541	[−1.138, 1.000]	.899
	Switch costs (accuracy)	0.000	0.000	[−0.001, 0.001]	.903
	Switch costs (drift rate)	0.002	0.003	[−0.003, 0.007]	.441
	Switch costs (nondecision time)	−0.100	0.491	[−0.871, 1.071]	.839
	Mixing costs (RT)	0.633	0.777	[−0.902, 2.168]	.416
	Mixing costs (accuracy)	0.000	0.000	[−0.001, 0.000]	.069
	Boundary separation for pure trials	0.000	0.002	[−0.002, 0.003]	.852
	Boundary separation for repeat trials	−0.001	0.002	[−0.005, 0.003]	.554
	Boundary separation for switch trials	0.000	0.002	[−0.005, 0.004]	.873
Trait Anxiety × WMC	Switch costs (RT)	0.463	0.494	[−0.513, 1.440]	.350
	Switch costs (accuracy)	0.000	0.000	[−0.001, 0.000]	.278
	Switch costs (drift rate)	0.000	0.002	[−0.004, 0.005]	.897
	Switch costs (nondecision time)	−0.200	0.453	[−1.095, 0.696]	.660
	Mixing costs (RT)	0.965	0.717	[−0.453, 2.382]	.181
	Mixing costs (accuracy)	0.000	0.000	[−0.001, 0.000]	.287
	Boundary separation for pure trials	0.001	0.001	[−0.004, 0.002]	.590
	Boundary separation for repeat trials	0.002	0.002	[−0.002, 0.006]	.264
	Boundary separation for switch trials	0.002	0.002	[−0.001, 0.006]	.215

Note. WMC = working memory capacity; RT = response time; DV = dependent variable.

Table 6

Summary of Interaction Effects of Anxiety and WMC on Task-Switching Using Bayesian Analyses

Interaction	DV	BF_{10}	BF_{01}	Evidence category for H_0
State Anxiety × WMC	Switch costs (RT)	0.310	3.226	Moderate
	Switch costs (accuracy)	0.318	3.147	Moderate
	Switch costs (nondecision time)	0.303	3.304	Moderate
	Switch costs (drift rate)	0.381	2.625	Anecdotal
	Mixing costs (RT)	0.375	2.669	Moderate
	Mixing costs (accuracy)	0.741	1.350	Anecdotal
	Boundary separation for pure trials	0.311	3.212	Moderate
	Boundary separation for repeat trials	0.332	3.012	Moderate
	Boundary separation for switch trials	0.295	3.384	Moderate
Trait Anxiety × WMC	Switch costs (RT)	0.462	2.163	Anecdotal
	Switch costs (accuracy)	0.533	1.877	Anecdotal
	Switch costs (nondecision time)	0.340	2.937	Anecdotal
	Switch costs (drift rate)	0.302	3.313	Moderate
	Mixing costs (RT)	0.662	1.510	Anecdotal
	Mixing costs (accuracy)	0.518	1.929	Anecdotal
	Boundary separation for pure trials	0.353	2.833	Anecdotal
	Boundary separation for repeat trials	0.524	1.910	Anecdotal
	Boundary separation for switch trials	0.590	1.694	Anecdotal

Note. WMC = working memory capacity; RT = response time; DV = dependent variable. The Bayes factor was computed based on comparison of the model with two main effects and the model with additional interaction terms (i.e., the interaction model), using a noninformative JZS default prior. The classification scheme for interpretation of the Bayes factors is based on Lee and Wagenmakers (2013).

tion and individual differences in response style, can influence and obscure the relation between anxiety and boundary separation. Fourth, it is noteworthy that although anxious individuals likely experience threatening TUT, we found that threatening or nonthreatening TUT do not mediate the relation between anxiety and task-switching performance. This finding is consistent with recent studies that have failed to find any relation between worry and cognitive performance, such as attention or executive functions (Forster et al., 2015; Harris, 2013; Moser et al., 2012). Moreover, given that attentional control theory de-emphasizes the mediating role of worrisome thoughts in the relation between anxiety and performance efficiency (Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011), our finding lends support for Derakshan and Eysenck's (2009) view that the relation between anxiety and task-switching efficiency may not be directly mediated by worrisome thought.

Despite the absence of a mediating effect of TUT on task-switching, however, it is notable that the frequency of TUT was associated with slower RT on all trial types in task-switching—that is, pure, $r = .221$, $p = .006$; repeat, $r = .221$, $p = .006$; and switch trials, $r = .189$, $p = .020$—that suggests that TUT may indiscriminately impair processing efficiency (RT) despite the different task demands associated with each type of trials in the task-switching paradigm. This may be because of lapsed attention caused by mind wandering (McVay & Kane, 2009). Given that the adverse effect of TUT on processing efficiency was not trial-specific, its effect on task-switching could have been cancelled out when switch costs were calculated between switch and repeat trials, both of which were similarly slowed by TUT.

Alternatively, switch and mixing costs might be more vulnerable to the intensity of worrisome thoughts than to their frequency. According to attentional control theory (Eysenck et al., 2007),

Table 7

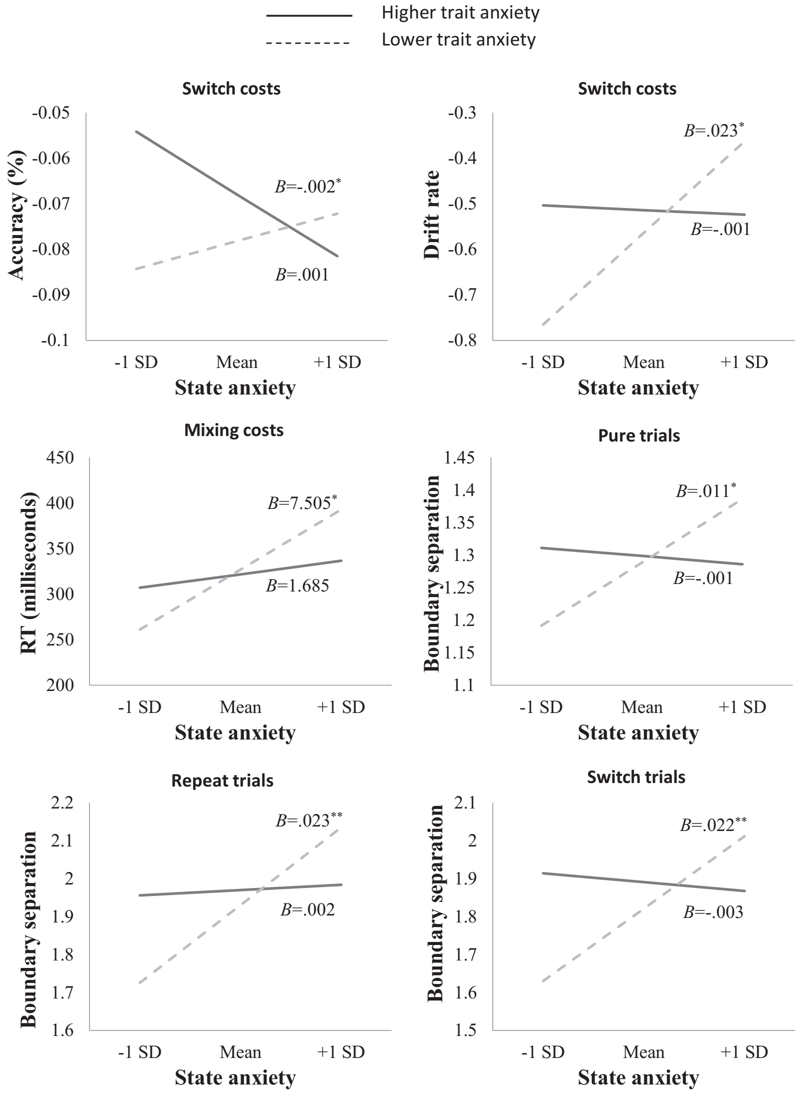
Summary of Interaction Effects of State and Trait Anxiety on Task-Switching Using Ordinary Least Squares Regression

DV	*B*	*SE*	95% CI	*p*
Switch costs (RT)	−0.0451	0.0986	[−0.2398, 0.1497]	.648
Switch costs (accuracy)	−0.0001	0.0000	[−0.0002, 0.0000]	.008
Switch costs (drift rate)	0.0013	0.0004	[−0.0022, −0.0004]	.004
Switch costs (nondecision time)	−0.1221	0.0905	[−0.3009, 0.0566]	.179
Mixing costs (RT)	−0.3166	0.1377	[−0.5886, −0.0445]	.023
Mixing costs (accuracy)	0.0000	0.0000	[−0.0001, 0.0000]	.234
Boundary separation for pure trials	−0.0007	0.0003	[−0.0012, −0.0002]	.012
Boundary separation for repeat trials	−0.0012	0.0004	[−0.0019, −0.0005]	.002
Boundary separation for switch trials	−0.0013	0.0004	[−0.0021, −0.0006]	.000

Note. DV = dependent variable; RT = response time; CI = confidence interval.

Figure 6

Simple Slopes (i.e., Unstandardized Coefficients) of State Anxiety Predicting Task-Switching When Trait Anxiety Was at Least 1 SD Above and Below the Mean



$^{*} p < .05.$ $^{**} p < .001.$

anxiety impairs task-switching because it allocates attentional resources to internal threat-related stimuli such as worrisome thoughts—that, in turn, result in the loss of attentional resources for ongoing task-switching. Given that attentional resources are distributed between concurrent task-switching and worrisome thoughts, it is crucial to investigate how the intensity of worrisome thoughts affects the allocation of cognitive resources. For instance, worries about potential failure on an important exam (e.g., a preemployment skills test) might require greater attentional resources than worries about potential failure on a practice exam. The different intensity of these worries, based on their potential implications, would affect one's performance to different degrees. In view of this, future studies are warranted to consider the intensity of worrisome thoughts in examining the mediating role of TUT on the relation between anxiety and task-switching. Further, it is important that future studies examine internal threat-related distractors beyond worrisome thoughts.

Lastly, we found that WMC did not moderate the relation between anxiety and task-switching performance. Although recent studies have found that WMC attenuates the adverse effect of trait anxiety on mathematical problem solving (Owens et al., 2014) and a memory task in the dual-task paradigm (Johnson & Gronlund, 2009), we failed to conceptually replicate the moderating effect of WMC on task-switching performance. This suggests that WMC might not protect individuals from impaired task-switching under anxiety. On the other hand, it is possible that the positive role of WMC in attenuating the negative effect of anxiety is task specific. For instance, an interaction between anxiety and WMC might only emerge when cognitive tasks demand the ability to maintain task-relevant information in the face of concurrent distractor interference, as in mathematical tests or dual tasks with high memory load (Raghubar et al., 2010; Redick et al., 2016). Given that task-switching paradigm relies more on an ability to resist proactive interference (Wylie & Allport, 2000), which is distinguished from the ability to resist distractor interference (Friedman et al., 2004), it is plausible that our findings of the null moderating effect of WMC may be attributed to different aspects of inhibitory control. Furthermore, although task-switching and WMC are often categorized under the umbrella term of executive functions, studies have demonstrated that task-switching costs (i.e., switch and mixing costs) implicate many cognitive processes that are distinct from those that underlie WMC (Miyake et al., 2000; Rubin & Meiran, 2005). Therefore, future studies should investigate how task demands would differently affect the moderating role of WMC in the relation between anxiety and other executive processes beyond task-switching.

Our study is not without limitations. Given that it focused on variations in naturally occurring state anxiety, the causality between anxiety and task-switching was not well established because of the lack of manipulation of state anxiety. Although most of our predictions were theoretically driven, future studies that experimentally manipulate state anxiety in the task-switching paradigm are warranted. Furthermore, given that we used only the color-shape task, it is important that future studies replicate our findings using other variants of the task-switching paradigm. Using more than one task would allow researchers to circumvent possible task impurity issues in the task-switching paradigm (Miyake et al., 2000). Moreover, given our findings of null associations of anxiety with boundary separation in mixed blocks and pure blocks and the one between trait anxiety and switch costs in RT, it is possible that our study may lack sufficient power to detect significant relations. Nevertheless, it is worthy highlighting the fact that the sample size of our study ($n = 152$) was larger than most of the previous studies: Ansari et al. (2008; $n = 59$); Derakshan et al. (2009; $n = 61$); Edwards et al. (2015; $n = 70$); Johnson and Gronlund (2009; $n = 50$); and Owens et al. (2014; $n = 96$). Thus, these results should be interpreted with caution.

Further, one might raise a methodological concern regarding our color-shape task. As the task used only two target stimuli and overlapping response mapping, a correct response for the shape task should always be wrong for the color task and vice versa. Given this, it is arguable that the use of only two stimuli may lead participants to engage in an idiosyncratic strategy to simply reverse one's response-key mapping from one key to another (i.e., a response key mapping-reversal strategy), instead of engaging in actual task-switching. However, this is unlikely for two reasons. First, the unpredictability of switch trials in our task renders the response key mapping-reversal strategy more inefficient, because the strategy requires that the participant correctly guess the type of trial (e.g., repeat or switch) and remember the preceding cue to reverse one's response successfully on a given trial. Second, given that our task cue always appeared before the target stimulus and not together, engaging in normal task-switching is easier and more efficient than simply reversing one's response keys while overriding the given task cue. In line with our view, we have observed robust switch and mixing costs—that should have been attenuated if the response key mapping-reversal strategy was used—and no participants reported using any unique strategy that was similar to the response key mapping-reversal strategy. Hence, we conclude that the use of only two stimuli with overlapping response key mapping does not invalidate the task used in our study.

In summary, this study elucidates several theoretical assumptions and predictions on the relation between anxiety and task-switching. Consistent with attentional control theory (Eysenck et al., 2007), we demonstrate that the locus of impaired switch costs under anxiety lies in task-set reconfiguration processes. We also find partial evidence for anxious individuals' use of compensatory strategies when performing task-switching. Our finding of the association between anxiety and mixing costs extends the literature by suggesting that anxiety affects not only transient control of task-set reconfiguration, but also global sustained control mechanisms in monitoring and maintaining two competing task sets during task-switching. Our mediation analyses indicate that the frequency of TUT does not mediate the adverse effect of state anxiety on task-switching. Moreover, WMC does not moderate the negative effect of anxiety on task-switching. Taken together, these findings contribute to more comprehensive understanding of the mechanisms that drive the relation between anxiety and task-switching.

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Appendix

Correlations Among Cognitive Variables

Table A1

Zero-Order Correlations Among Cognitive Variables

Variable	1	2	3	4	5	6	7
1. Working memory capacity (PCU)	—						
2. Switch costs (RT)	−.043	—					
3. Switch costs (accuracy)	−.087	−.146	—				
4. Switch costs (binning)	.056	.475*	−.841*	—			
5. Mixing costs (RT)	−.172*	.321*	−.264*	−.273*	—		
6. Mixing costs (accuracy)	.106	−.012*	.210*	−.359*	.008	—	
7. Mixing costs (binning)	−.175*	.172*	.100	−.010*	.768*	−.301*	—

Note. PCU = partial-credit unit; RT = response time.

$^{*} p < .05$.