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Test Anxiety and Children's Working Memory Task Performance:
Does Trait or State Anxiety Matter More?

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Abstract

This study examined the effect of trait test anxiety versus state anxiety on children's mental arithmetic task performance. Participants (*N* = 113; 11-year-olds) completed a mental arithmetic and memory recall task under high and low situational stress conditions. State anxiety was assessed using both self-report and physiological (i.e., cortisol) measures. Measures of task accuracy and accuracy/response time served as indicators of performance effectiveness and processing efficiency. The growth modelling approach was used to examine patterns of change in cortisol levels across time. The key finding of this study is that trait test anxiety has a direct and detrimental effect on working memory task performance. This effect was not mediated by state anxiety, regardless of whether the role of trait test anxiety was examined in conjunction with self-reported or physiological state anxiety. Our findings provide further evidence in support of attentional control theory.

Keywords: Attentional control theory, processing efficiency theory, dual-task performance, academic achievement.

Test Anxiety and Children’s Working Memory Task Performance:
Does Trait or State Anxiety Matter More?

Test anxiety is a situation-specific form of anxiety that occurs when individuals perceive an examination as a threatening experience and feel that they do not have sufficient resources to perform well (Zeidner, 1998). Research has shown that test anxiety correlates negatively with performance on aptitude and achievement measures (e.g., Hembree, 1988; McDonald, 2001). These findings suggest that test anxiety could jeopardize the validity of examination results because test-anxious individuals’ performance may not reflect their true abilities (Zeidner, 1990).

Although test anxiety has been extensively researched, much of this work has been conducted with undergraduates (McDonald, 2001). Given the high prevalence of test anxiety among school-aged children (Segool, Carlson, Goforth, Von Der Embse, & Barterian, 2013) and the disruptive effects of test anxiety on children’s academic careers (Ergene, 2003), more child-based studies are needed to bridge the gap in our knowledge about the impact of test anxiety in the early years of formal education. In view of the paucity of test anxiety intervention research on children (Ergene, 2003; Von Der Embse, Barterian, & Segool, 2013), this line of research would also contribute to the establishment of an empirical base for the development of effective interventions to ameliorate test anxiety in the early years of formal education.

Test Anxiety and Cognitive Performance

Our current investigation of the effects of test anxiety on children’s working memory performance is guided by two theoretical frameworks: attentional control theory (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007) and processing efficiency theory (PET; Eysenck & Calvo, 1992). Although both theories were developed to account for the effects of general anxiety on cognitive performance, they have been applied to test anxiety (Eysenck et al., 2007, p. 336; Mowbray, 2012). A central assumption of both theories is that task performance can be assessed in terms of effectiveness and efficiency. Effectiveness refers to the quality of task performance and is typically operationalized as response accuracy. Efficiency is defined as the relationship between accuracy and the resources used to accomplish the task; it can be measured by the ratio of accuracy to response time on correct trials (Hoffman, 2012).

Both theories propose working memory (WM; Baddeley, 1986, 2001) as the mechanism underpinning the effects of anxiety on cognitive performance. According to PET, anxiety leads to an increase in worry (i.e., cognitions about how one's performance will be judged by others), which consumes WM capacity and leaves a smaller functional capacity for the task at hand. The ACT expands on this explanation by specifying that anxiety increases the allocation of attentional resources to worry, thus reducing attentional focus on the current task. The ACT further specifies that worry motivates anxious individuals to compensate for the restricted availability of WM by increasing their effort (e.g., allocate additional processing resources) and using auxiliary resources or strategies (e.g., rote learning or articulatory rehearsal). As a consequence, anxiety typically impairs efficiency to a greater extent than it does effectiveness. An extensive body of research provides empirical support for the proposed negative links between anxiety and WM functioning (for a review, see Berggren & Derakshan, 2013; Eysenck & Derakshan, 2011).

Trait Test Anxiety and State Anxiety

In line with Spielberger's (1972) distinction between the general constructs of trait and state anxiety, test anxiety is similarly divided into two dimensions (Sarason, 1972). Trait test anxiety refers to an individual's disposition to perceive test situations as threatening and to respond to such threats with state anxiety (i.e., transient feelings of negative arousal). The PET and ACT both assume that state anxiety is determined interactively by trait anxiety and situational stress. Within the context of test anxiety, this implies that when highly trait test-anxious individuals are faced with a stressful, test-like situation, their levels of state anxiety will increase. In contrast, low trait test-anxious individuals facing a similar situation would not report an increase in state anxiety.

Notably, the PET and ACT have differing views about the relative importance of these two dimensions as predictors of cognitive performance. On the one hand, PET clearly states that elevated state anxiety is key to "…determining individual differences in internal processing and performance" (Eysenck & Calvo, 1992; p. 414). In contrast, ACT posits that anxiety, whether regarded as a personality dimension (i.e., trait anxiety or test anxiety) or as a transient emotional state, is associated with performance impairments on cognitive tasks (Eysenck & Derakshan, 2011). Empirical support for both views have been reported in the literature. A number of studies have found significant effects of state anxiety on backward digit span (Hadwin, Brogan, & Stevenson, 2005), a task switching paradigm (Derakshan, Smyth, & Eysenck, 2009) and an inhibition task based on the go/no-go paradigm (Pacheco-Unguetti, Acosta, Lupianez, Roman, & Derakshan, 2012). Others have reported a significant negative relation between trait anxiety and academic performance (via lowered WM capacity) in 11- to 13-year-olds (Owens, Stevenson, Hadwin, & Norgate, 2012; Owens, Stevenson, Norgate, & Hadwin, 2008).

However, a number of methodological limitations in the abovementioned and other studies (e.g., the absence of a situational stress manipulation and assessment of state anxiety) have made it difficult to establish whether observed performance impairments are due to trait anxiety or elevated state anxiety levels (Ng & Lee, 2015). To our knowledge, only a handful of studies have investigated the effects of both trait and state anxiety on WM functioning. Of these, four studies have reported direct detrimental effects from trait anxiety. In two studies, Ng and Lee (2010, 2015) assessed 11-year-olds' trait test anxiety and experimentally manipulated state anxiety to examine the independent and joint contributions of these variables to WM task performance. In both studies, children who reported higher levels of trait test anxiety performed more poorly on the WM task; there were no significant effects of state anxiety. Pacheco-Unguetti, Acosta, Callejas, and Lupianez (2010) found an adverse effect of high trait anxiety on executive control in undergraduates, after controlling for differences in state anxiety. In another study involving 9- to 12-year-olds, Ursache and Raver (2014) demonstrated that higher levels of trait (not state) anxiety were associated with poorer performance on shifting and inhibition tasks.

A common element of the abovementioned studies is that state anxiety was measured using self-report instruments, such as the State-Trait Anxiety Inventory for Children (Spielberger, 1973). Although *self-reported* or experienced state anxiety may be important, such measures are also susceptible to artefacts faced by other self-report measures (e.g., response biases), especially when it is not always possible to mask completely the true aim of experiments involving manipulation of state anxiety. Consequently, self-report instruments may provide inaccurate data regarding actual state anxiety levels. In this regard, *physiological* measures are a useful supplement to self-report measures in terms of providing a more objective assessment of state anxiety in response to a stressful experience.

Cortisol (a glucocorticoid hormone) is recognized as a reliable marker of physiological stress (Kirschbaum & Hellhammer, 1989). Stress-related activation of the hypothalamic-pituitary-adrenal (HPA) axis causes a cascade of endocrine events, which results in the production of cortisol in the adrenal cortex. Of particular relevance to the current study is the idea that cortisol has detrimental effects on WM task performance (e.g., Barsegyan, Mackenzie, Kurose, McGaugh, & Roozendaal, 2010; Lupien, Gillin, & Hauger, 1999), due to the high density of glucocorticoid receptors in the prefrontal cortex (Petrides, 2000). These ideas suggest that cortisol is an important variable to consider in studies examining the effects of anxiety on WM task performance.

Several studies have found a link between cortisol and WM functioning by comparing the WM task performance of participants in control versus stress groups. For example, Oei, Everaerd, Elzinga, Van Well, and Bermond (2006) investigated the effects of acute psychosocial stress (induced by the Trier Social Stress Test) and cortisol responses on the Sternberg item-recognition task, which required participants to hold target letters in memory for later recognition. Processing load was defined by the number of targets (1 to 4) to hold in WM multiplied by the number of stimuli (1 to 4) in the item-recognition display (for more details, see Lupien et al., 1999). Compared to the control group, the stress group had higher levels of cortisol and slower task reaction times. Schoofs, Preuß, and Wolf (2008) reported the same pattern of findings in a study of the effects of acute psychosocial stress on numerical *n*-back task performance. Although these findings provide some insights about the importance of HPA axis activation and cortisol release for impairment on WM tasks, they did not consider the role of trait anxiety as a predictor of WM task performance, either on its own or in conjunction with cortisol. We addressed this issue in the current study.

The Current Study

In our preceding review, we highlighted the limitations of previous studies examining the relative contributions of trait versus state anxiety on WM task performance, as well as the limitations of using self-report measures of state anxiety. The aim of the current study is to address these gaps within the specific context of test anxiety. Building on previous work by Ng and Lee (2015) and recent findings showing detrimental effects of cortisol on WM task performance, we assessed children's trait test anxiety and their responses to a situational stress manipulation using self-report and physiological measures of state anxiety. Children's WM task performance were assessed using Ng and Lee's (2015) loading paradigm, whereby a mental arithmetic task is performed simultaneously with a memory recall task. Task performance is dependent on WM resources to manage the processing and storage demands of both tasks.

Based on the assumption that state anxiety is determined interactively by trait anxiety and situational stress (Eysenck & Calvo, 1992; Eysenck et al., 2007), we derived two hypotheses about the roles of trait test anxiety and state anxiety as predictors of task performance. Drawing on PET and ACT's emphasis on the role of state anxiety, we argue that the effect of state anxiety on cognitive performance can be conceptualized as a moderated mediation model. This model specifies that the effect of a mediator (M) in the relation between X and Y is moderated by another predictor (Z). Thus, Hypothesis 1 states that the effect of trait test anxiety (X) on WM task performance (Y) is mediated by state anxiety (M), but only when situational stress (Z) is high. This is because elevations in state anxiety are expected to occur only at high, but not low, situational stress. Given that ACT also emphasizes the role of the trait dimension of anxiety, we interpreted this proposition to indicate that trait test anxiety will have a direct effect on WM task performance regardless of state anxiety levels (Hypothesis 2).

Regarding the locus of the test anxiety effect on the loading paradigm, previous studies have reported mixed findings. Ng and Lee (2010) found adverse effects of trait test anxiety on memory task efficiency. In contrast, a later study (Ng & Lee, 2015) found trait test anxiety to impair both mental arithmetic accuracy and efficiency. The current study explored the extent to which trait test anxiety and state anxiety affected memory recall and mental arithmetic performance.

We focused our investigation on 11-year-olds for a number of reasons. First, as noted by Hembree (1988, p. 75), test anxiety is “small to non-existent in the very early grades but firmly in place by grade 5”. Moreover, previous findings (Hembree, 1988; Hill & Sarason, 1966) indicated that test anxiety begins to affect children’s performance from fourth grade (i.e., age 10). Second, 11-year-olds are likely to possess the cognitive ability to understand relatively complex task instructions and to perform two concurrent tasks as required within the loading paradigm. Thus, our targeted age group is well-suited for an investigation of the impact of test anxiety on children’s cognitive performance.

Method

Participants and Design

Principals of public primary schools serving families with low- to middle-socioeconomic-status backgrounds in Singapore were invited to participate via email. At each of the 5 participating schools, parental consent forms were distributed to a class of Primary Five children (average class size: 40). Each class reported a 50% to 60% consent rate, resulting in 113 participants (M_{age} = 11.25 years, *SD* = 0.52; 54 boys). All participating children provided written assent. We manipulated situational stress (low versus high) on a within-subjects basis. Trait test anxiety was assessed and served as a continuous predictor in analyses. Accuracy and RT on the memory recall and mental arithmetic tasks served as dependent measures. Accuracy scores were used as measures of performance effectiveness. Following Townsend and Ashby’s (1983) approach (see also Hoffman, 2012), accuracy divided by RT (summed across all accurate trials) was used as measures of efficiency; higher scores on the latter indicate increased efficiency.

Experimental Task

Two parallel versions of the experimental task were created—one version was administered in the high situational stress condition and the other in the low situational stress condition. The task consisted of 32 trials presented in four blocks of 8 trials each. Data from a fifth block (6 trials) were not used in our analyses (see explanation in the next section). In each trial, participants were first presented with a 5-letter memory load set (see Figure 1), which consisted of a contiguous alphabet sequence presented in randomized order (e.g., “PRTQS”). The memory load set remained on the computer screen until participants indicated via keypress that they had memorized the 5 letters. Then, participants immediately recalled the memory load set by typing their responses on the keyboard. Participants were then instructed to repeat the memory load set aloud while solving a mental arithmetic problem. They were told to provide their answers to the arithmetic problem by providing the units first, followed by the tens and the hundreds by clicking on boxes numbered 0 to 9 on the computer screen using a mouse (e.g., the correct responses for 624 – 296 are “8”, “2”, and “3”). This reduces the need to maintain intermediate results in memory, thus removing a potential source of interference during the maintenance of the memory load set. After solving the arithmetic problem, participants recalled the memory load set by typing their responses on the keyboard. All stimuli were presented on a computer using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002).

Manipulation of Situational Stress

The situational stress manipulation is based on a protocol developed by Ng and colleagues, which has been shown to successfully elevate state anxiety levels in 11-year-olds (Ng & Lee, 2010, 2015). In the high situational stress condition, participants were informed that the task was a test and that they would receive performance feedback after each trial. False feedback was provided to simulate a situation in which children experienced repeated failure despite their best efforts (Dickerson & Kemeny, 2004). Upon completion of each trial, feedback was presented on the computer screen as a bar graph. Green and red bars represented success and failure feedback, respectively. Children were told that success was contingent upon providing the correct answer as quickly as possible, whereas incorrect answers or the inability to provide the correct answer sufficiently quickly was associated with failure. We associated a purported speed criterion (i.e., children's speed of response was compared against other children) to increase the likelihood that participants would perceive the feedback as credible.

The first four blocks of trials were engineered to provide negative feedback on 75% of the trials and positive feedback on the remaining trials. Within each block of 8 trials, there were 6 negative feedback trials and 2 positive feedback trials. Feedback was presented in a predetermined order (i.e., not random) to ensure that positive feedback trials were interspersed among negative feedback trials. In the fifth block, the ratio was reversed so that participants received more positive than negative feedback. This was used to ameliorate the effect of the negative feedback on the children's emotional state. In the low situational stress condition, participants were informed that the task was not a test. Performance feedback was not provided at all in this condition.

Measures

Trait test anxiety. The Test Anxiety Inventory (TAI; Spielberger et al., 1980) consisted of 20 statements describing various reactions towards tests and examinations (e.g., “I feel confident and relaxed while taking tests”). Participants rated how they generally felt about each statement on a scale of 1 (*almost never*) to 4 (*almost always*). TAI scores range from 20 to 80; higher scores reflect higher levels of trait test anxiety. In the current sample, internal consistency of the TAI was high with a Cronbach’s alpha of .85.

Self-reported state anxiety. The State-Trait Anxiety Inventory for Children (STAIC; Spielberger, 1973) consisted of 20 statements describing various emotional states (e.g. calm, upset, nervous). Each statement began with the phrase “I feel ____” followed by three options (e.g., 1. very calm, 2. calm, 3. not calm). Participants used the numeric keypad to select the option that best described how they felt at the present moment. The STAIC was administered immediately before (pre-test) and after (post-test) the experimental task. Test items were presented in a different order at each assessment. STAIC scores range from 20 to 60; higher scores reflect higher levels of state anxiety. All items were presented on a computer using E-Prime 2.0 (Schneider et al., 2002). For the main analyses, a change score was derived per participant by subtracting the pre-test score from the post-test score. Increased state anxiety is indicated by positive change scores, with larger scores reflecting a greater increase in self-reported state anxiety.

Physiological state anxiety. Using the passive drool method, saliva samples were obtained at baseline (i.e., prior to presentation of task instructions), immediately after completing the experimental task (average completion time: 38 min), and at 10 and 20 min following the end of the experimental task. All samples were immediately stored in a cooler bag and later frozen at -80^{0}C in the laboratory until assay. Cortisol assays were conducted in duplicate using an expanded range, high sensitivity, salivary cortisol enzyme immunoassay kit (Salimetrics, 2013). Optical density was read on a standard plate reader at 450 nm. Enzyme immunoassays were run according to manufacturer instructions and average intra- and inter-assay coefficients were less than 10% and 15%, respectively. Standard curve and concentration of cortisol in saliva samples was generated according to manufacturer's instructions using a 4-parameter non-linear regression curve fit. At each time point, mean value of cortisol across the two assays was used for analyses.

Procedure

All tasks and measures were administered on a one-on-one basis over three sessions, spaced at least two days apart. During the first session, the TAI was administered first, followed by a practice version (10 trials) of the experimental task. In the remaining sessions, the experimental task was administered under high or low situational stress conditions. The order of presentation of the two conditions was counterbalanced across participants. The practice task was administered in a separate session to minimize the influence of practice task performance on children's state anxiety and achievement on the experimental task.

In both high and low situational stress conditions, participants first completed a pre-test version of the STAIC and provided a baseline saliva sample. Then participants received a set of task instructions corresponding to the experimental condition that they had been assigned to. After that, the experimental task was administered. To ensure that the mental arithmetic and memory recall tasks were given equal priority, participants were told to maintain a high level of accuracy on both tasks. Upon completion of the experimental task, participants completed the post-test version of the STAIC and provided post-test saliva samples.

To accommodate participants' class schedules, we conducted the study at various times throughout the day (8:00 AM to 3:30 PM; *M* = 12:26 pm, *SD* = 2 hr 15 min). Forty-four participants (40%) were assessed in the morning. Preliminary analyses showed that the time-of-day at which the study was conducted (indexed by baseline sample collection time) correlated with cortisol levels in the high situational stress condition, particularly at immediate post-test, $r(112) = .21$, and 10-min post-test, $r(112) = .21$, $ps < .05$. No other correlations attained significance ($ps > .05$). Given these results, baseline sample collection time was included as a covariate in the growth model for the high situational stress condition (see details in the next section).

Analysis Plan

Our main dependent measures were mental arithmetic accuracy and response time (RT) as well as memory recall accuracy and RT. Memory recall accuracy was defined as the total number of trials with correct responses on both the encoding and recall components of the task. All analyses were conducted using MPlus version 7 (Muthen & Muthen, 1998-2012).

We conducted two sets of analyses to ascertain the relations between trait test anxiety and state anxiety with mental arithmetic and memory recall performance. First, we ran a series of path analyses to test our hypotheses on *self-reported state anxiety*. Separate path models (see

Figure 2) were constructed for accuracy and efficiency because anxiety-related deficits were expected to have primary effects on efficiency, but not accuracy (Eysenck & Calvo, 1992; Eysenck et al., 2007). State anxiety was modeled using a variable that indexes the change in state anxiety from pre-test to post-test. In accordance with theory (Eysenck & Calvo, 1992; Eysenck et al., 2007), the change in state anxiety was modeled as being affected jointly by trait test anxiety and situational stress.

In Ng and Lee's (2015) experimental setup, the mental arithmetic task was sandwiched between the presentation and recall components of the memory recall task. Consistent with their argument that participants must share or shift WM resources across the two tasks, Ng and Lee (2015) found a significant, bidirectional relationship between mental arithmetic and memory recall performance. Because our experimental setup mirrors Ng and Lee's (2015) version, we also specified a correlational path between mental arithmetic and memory recall performance. In view of the inconsistent findings regarding the locus of the test anxiety effect on WM task performance, we specified paths from trait test anxiety and state anxiety to memory recall and mental arithmetic performance to explore the relations amongst these variables. All analyses were conducted using the bootstrap option to account for the expected skewness in the interaction term.

In the second set of analyses, we conducted a series of latent growth curve analyses to test our hypotheses on *physiological state anxiety*. To model inter-individual variability in cortisol trajectories at low and high situational stress, we fitted separate growth curves for data from each experimental condition (see Figure 3). Within each experimental condition, growth coefficients were estimated freely to correspond to the unique characteristics of the data (Curran, Obeidat, & Losardo, 2010, p. 127). The key components of a growth model are the intercept (i.e., starting point) and slope (i.e., rate of change). In this study, the intercept is defined as the level of cortisol at immediate post-test. The slope is defined by the average rate of change in cortisol levels after stress exposure (i.e., from immediate post-test to 20 min post-test). Both the intercept and slope were allowed to vary across individuals. Cortisol levels at baseline, which represent pre-stress exposure levels of cortisol, were modelled as antecedents and were specified to predict the intercept and slope. Given the significant correlations between baseline sample collection time and cortisol levels (at immediate post-test and 10-min post-test) in the high situational stress condition, correlational paths were specified between sample collection time and the intercept and slope at high situational stress.

After specifying a growth curve for each experimental condition, we tested our hypotheses by examining the relations between the intercept and slope terms with individual differences in trait test anxiety, mental arithmetic and memory recall performance. The predictive paths in Figure 3 parallel those in the path analysis models (in Figure 2). Specifically, paralleling the path from trait test anxiety to state anxiety (change) in Figure 2, trait test anxiety was modeled to predict the intercept and slope terms to reflect the effect of trait test anxiety on physiological state anxiety. Second, the slope term (i.e., rate of change in cortisol) was modelled to predict mental arithmetic and memory recall accuracy and efficiency. Third, trait test anxiety was modelled to have direct effects on mental arithmetic and memory recall accuracy and efficiency, as stated in Hypothesis 2. It is important to note that situational stress was not modelled explicitly as a variable in the growth models. Instead, its effects were inferred from findings from separate models that differed by whether equality constraints were placed on parameters (marked H1 and H2 in Figure 3) across the low and high situational stress models. A significant deterioration in model fit when constraints were placed indicated a significant effect of situational stress.

Results

Preliminary Analyses

Data screening for multivariate outliers using Mahalanobis distance ($p < .001$) was conducted separately for the accuracy and efficiency measures. For both measures, one case was identified as a multivariate outlier and deleted, leaving 112 cases for analysis. A 2 (task order: high vs. low situational stress first) x 2 (situational stress: high vs. low) within-subjects ANOVA revealed no significant main effect of task order on self-reported state anxiety change, memory recall accuracy, math accuracy, memory recall efficiency, and math efficiency, all *Fs*(1, 110) < 2 and all *p*s > .05. For physiological state anxiety/cortisol levels, a 2 (task order: high vs. low situational stress first) x 2 (situational stress: high vs. low) x 4 (time: pre-test vs. immediate post-test vs. 10-min post-test vs. 20-min post-test) within-subjects ANOVA also revealed no significant main effect of task order, $F(1, 110) = 1.42$, $p > .05$. These results show that children's self-reported and physiological state anxiety as well as task performance were not influenced by order of exposure to the high and low situational stress conditions.

Table 1 presents the descriptive statistics of the study variables. In the low situational stress condition, trait test anxiety significantly correlated with math efficiency, $r(112) = -.25$, $p < .05$; math accuracy correlated with recall accuracy, $r(112) = .44$, $p < .05$, and math efficiency correlated with recall efficiency, $r(112) = .35$, $p < .05$. Cortisol levels at all 4 time points were positively correlated with each other, *r*s ranged from .47 to .86, *p*s < .05. In the high situational stress condition, math accuracy significantly correlated with recall accuracy, $r(112) = .24$, $p < .05$, and recall efficiency correlated with math efficiency, $r(112) = .53$, $p < .05$, and baseline cortisol, $r(112) = .20$, $p < .05$. Cortisol levels at all 4 time points were positively correlated with each other, *r*s ranged from .41 to .89, *p*s < .05.

As a manipulation check, the effect of the situational stress manipulation on self-reported state anxiety and cortisol were analyzed separately. The self-reported state anxiety data was analyzed using a 2 (situational stress: low vs. high) x 2 (time: pre-test vs. post-test) repeated-measures ANOVA. The main effect of situational stress was not significant, $p > .05$. The significant main effect of time was qualified by a significant interaction, $F(1, 111) = 6.34$, $p < .05$, partial $\eta^2 = .05$. There were larger increases in self-reported state anxiety levels in the high situational stress condition compared to the low situational stress condition (see means in Table 1).

The average cortisol trajectory of raw data is presented in Figure 4. The cortisol data was analyzed using a 2 (situational stress: low vs. high) x 4 (time: pre-test vs. immediate post-test vs. 10-min post-test vs. 20-min post-test) repeated-measures ANOVA. Because Mauchly's test indicated that the assumption of sphericity was violated for all effects involving time, the Greenhouse-Geisser correction for *df* values were reported. Only the main effect of time was significant, $F(1.8, 195.9) = 3.27$, $p < .05$, partial $\eta^2 = .03$. Cortisol values at each time point were collapsed across situational stress conditions and subjected to post-hoc paired samples *t*-tests to test for differences between consecutive assessments of cortisol. Cortisol levels significantly decreased from immediate post-test ($M = 16.25$) to 10 min post-test ($M = 15.32$), $t(111) = 3.72$, $p < .05$. No other comparisons attained significance (*p*s > .05). Taken together, these results indicate that our experimental manipulation increased state anxiety from pre-test to post-test, as far as self-reported state anxiety is concerned.

Results of Path Analyses

As shown in Figure 5, our findings provided support for Hypothesis 2. Trait test anxiety had a direct, negative effect on mental arithmetic efficiency. In other words, this effect was not mediated by state anxiety change, nor was it dependent on situational stress condition (high vs. low). We found little support for Hypothesis 1; for both accuracy and efficiency models, all the component paths of the moderated mediation effect were not statistically significant, except the path from situational stress to state anxiety change.

Results of Latent Growth Curve Analyses

As shown in Figure 3, performances in the high and low situational stress condition were considered together in two models: with all paths estimated freely versus paths specified in Hypotheses 1 and 2 constrained to be equal. For both accuracy and efficiency measures, equality-constrained models provided similar fit as the freely estimated models and were more parsimonious (accuracy: $\triangle\chi^2$ (6) = 7.35, p = .29; efficiency: $\triangle\chi^2$ (6) = 6.69, p = .35). Table 2 presents the parameter estimates of the equality-constrained models.

In the equality-constrained model for accuracy, there were no significant relations between trait test anxiety, cortisol slope and the accuracy measures. In the equality-constrained model for efficiency, trait test anxiety was negatively related to mental arithmetic efficiency: the standardized estimate for the low situational stress condition was -0.14 (95% CI [-0.25, -0.01]), and the corresponding estimate for the high situational stress condition was -0.19 (95% CI [-0.36, -0.03]). Notably, no other paths attained significance.

Discussion

The main aim of this study was to investigate the effect of trait test anxiety and state anxiety on a mental arithmetic and memory recall task that depends on WM resources. Taking into consideration the limitations of previous studies, we addressed this question by assessing children's responses to a situational stress manipulation using two different measures of state anxiety. Path and growth modelling analyses revealed that both self-reported and physiological state anxiety were not associated with trait test anxiety or any of the WM task performance measures. Trait test anxiety emerged as the key predictor of WM task performance, regardless of whether its role was examined in conjunction with self-reported or physiological state anxiety.

The results of the manipulation check showed that children reported a larger change in self-reported state anxiety at high (relative to low) situational stress, regardless of their trait test anxiety levels. In contrast, cortisol levels did not show a significant elevation from baseline to any of the post-test time points, although there was a significant overall decrease from immediate post-test to 10-min post-test. Growth modelling analyses revealed no significant change in cortisol across the three post-test time points (see Table 3). On the one hand, our self-reported state anxiety results are in line with previous studies (Ng & Lee, 2015) and provide further evidence of the efficacy of the stress manipulation protocol in increasing children's experienced state anxiety. However, the non-significant differences in physiological state anxiety cast some uncertainty on the protocol's effectiveness in eliciting a cortisol response. This has implications for the interpretation of our results; we return to this point later.

The path analyses revealed a direct effect of trait test anxiety on mental arithmetic efficiency, which was not influenced by self-reported state anxiety or situational stress. These results replicate previous findings demonstrating that participants' perception of their state anxiety levels did not mediate the effects of general trait anxiety (e.g., Pacheco-Unguetti et al., 2010; Ursache & Raver, 2014) and trait test anxiety (Ng & Lee, 2010, 2015) on WM task performance. Our current study employed a similar stress manipulation protocol and WM task as Ng and Lee. Thus, viewed collectively, our findings suggest that the effect of trait test anxiety on WM task performance is relatively robust and lend further support to the theoretical notion that heightened trait anxiety is associated with impaired WM functioning (Eysenck et al., 2007).

Analogous to the self-reported state anxiety data, growth modelling analyses revealed a direct effect of trait test anxiety on mental arithmetic efficiency. Compared to the freely estimated model, the equality-constrained model was more parsimonious, indicating that the size of the effect of trait test anxiety on mental arithmetic efficiency did not differ across high and low situational stress. However, these findings should be interpreted with caution because we did not observe significant changes in cortisol levels in response to the situational stress manipulation. Specifically, given the non-significant change in cortisol, it is not clear whether the effect of trait test anxiety on mental arithmetic efficiency is mediated by changes in physiological state anxiety. More generally, our findings are in contrast to previous reports of significant relations between stress-induced cortisol and impairment on WM tasks (e.g., Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011; Schoofs et al., 2008; Schoofs, Wolf, & Smeets, 2009).

The non-significant effect of situational stress manipulation on cortisol was surprising, given that the protocol included elements of social evaluation (e.g., provision of performance feedback), which has been shown to be effective in eliciting a cortisol response (Dickerson & Kemeny, 2004). Gunnar, Talge, and Herrera (2009) noted that previous research on cortisol reactivity, particularly in children younger than 13 years of age, has produced mixed results and it remains unclear why some studies were successful in producing cortisol responses while others were not. Within the context of this study, a possible explanation is that our stress manipulation protocol lacked a salient and age-appropriate element of social-evaluative threat, such as the presence of a "teacher" to evaluate children's performance during the study (Jansen et al., 2000). This is in line with Yim, Quas, Cahill and Hayakawa’s (2010) argument about the importance of creating a context that is centrally related to children's lives (i.e., being evaluated in school) in order to induce cortisol responses successfully. It will be useful to incorporate this "teacher" element in future studies.

The dissimilar findings may also be due to cross-study differences in the stressor tasks. Schoofs et al. (2009) used a physical stressor (i.e., a cold pressor task) whereas we employed a psychological stressor in the form of a cognitive task. Although both types of stressors have been shown to activate the HPA axis, the pathways through which this is achieved are different (McRae et al., 2006). The HPA response to psychological stressors involve the limbic stress pathways, but physical stressors involve the visceral efferent pathways. In a similar vein, Shackman et al. (2006) suggested that physical stressors primarily amplifies individuals’ attention to the physiological symptoms of anxiety whereas psychological stressors tend to increase verbal rumination and worry. The two stressor types also differ in duration of stressor exposure (i.e., physical stressors are shorter in duration), which may influence the magnitude of the cortisol response (McRae et al., 2006). Taken together, the varying characteristics of physical versus psychological stressors suggest that findings derived from these stressor paradigms may not be directly comparable. A possible avenue for future research is to compare responses to these two stress manipulations in the same individuals and to determine whether physical and psychological stress responses predict WM task performance in a similar way.

Although the current study found no significant effects of cortisol on WM task performance, we argue that it provides an important and alternative perspective of individuals' responses to an acute psychological stressor for two reasons. A key contribution of the cortisol measure is in providing an assessment of state anxiety that is less susceptible to response biases. Second, cortisol data is important for delineating the physiological mechanisms underlying the effects of anxiety on WM task performance. Although theoretical frameworks have been proposed to describe the role of cortisol on cognitive performance (Arnsten, 2009), it is clear that more research is needed to address the issues discussed above. In a similar vein, we argue that the growth modelling approach is particularly useful for analysing change in physiological state anxiety. In addition to providing mean estimates of cortisol levels at a pre-determined starting point (i.e., intercept) as well as the average rate of change in cortisol over time (i.e., slope), it also provides information on between-person variability in the intercept and slope cortisol (Curran et al., 2010). Together, these estimates provide a more accurate representation of the patterns of change in cortisol in response to stress. Thus, we encourage others to employ the methods described here to explore the relative contributions of trait and state dimensions of anxiety on WM task performance.

Limitations and Future Directions

One limitation of our study is its relatively small sample size. Although there are no hard and fast rules, some researchers have recommended a minimum sample size of 200 for structural equation models (Barrett, 2007). Of particular concern here is the results of our growth modelling analyses, which involve complex models with many parameters. Based on Davison and Hinkley's (1997) recommendation, we re-ran our analyses using bootstrap methods to account for the small sample size. Notably, the bootstrap results are very similar to our original results, which suggest that our current findings are reliable. Nevertheless, we encourage replication and further investigation in future studies using a larger sample size to examine the robustness of our findings.

Our study showed that self-reported state anxiety and cortisol were weakly correlated with each other. This was an unexpected finding given that physiological and psychological responses theoretically represent indicators of the same construct (so a strong association between both measures was expected). A possible explanation for this finding is that the low correlations represent a time-lag effect (Schlotz et al., 2008) as a result of the different time courses and dynamics of the two stress responses. According to Schlotz et al. (2008), self-reported state anxiety responses occur within seconds and may change dynamically during a prolonged stress episode whereas cortisol responses reach their peak approximately 15 to 20 minutes after stressor onset and change less dynamically. An interesting avenue for further research is to explore individual differences in stress response patterns and the extent to which response dissociation is associated with anxiety.

From an applied perspective, our current findings suggest that intervention efforts should be directed at children with heightened trait test anxiety. Drawing on the ACT framework, efforts that focus on improving WM functions such as cognitive and attentional control (e.g., Roughan & Hadwin, 2011, Sari, Koster, Pourtois, & Derakshan, in press), or training highly trait test-anxious children to divert their attention away from anxiety-related stimuli (e.g., Sass, Evans, Xiong, Mirghassemi, & Tran, in press) could potentially decrease anxiety-related performance deficits. Mowbray’s (2012) review of possible interventions based on ACT provides a useful starting point for future intervention-based studies.

Conclusions

The current study contributes to our understanding of the relative contributions of trait test anxiety and state anxiety on children’s WM task performance. Utilizing a research design that allowed for an examination of the effect of both trait and state anxiety, our study clearly showed that children’s state anxiety levels (whether perceived or physiological in nature) did not contribute to individual differences in WM task performance; what matters more is their dispositional tendency to feel anxious in the current situation. From a theoretical perspective, these findings further strengthens ACT’s claim that trait anxiety plays a key role in the effects of anxiety on cognitive task performance.

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Table 1

Descriptive Statistics and Pearson's Product-Moment Correlation Matrix between the Anxiety, Cortisol, Accuracy and Efficiency Measures at Low and High Situational Stress Conditions (N = 112)

	Low Situational Stress		High Situational Stress	
Variable	M	SD	M	SD
Trait test anxiety[a]	46.41	9.62	—	—
State anxiety (pre-test)	34.59	7.22	34.46	7.81
State anxiety (post-test)	34.67	7.23	36.44	6.71
StateChange	0.64	5.05	4.46	7.18
Math accuracy	25.54	6.05	25.64	4.91
Recall accuracy	22.28	5.25	21.79	5.32
Math efficiency	8.76	3.87	7.22	2.60
Recall efficiency	25.11	6.71	25.45	6.05
Cort. (baseline)	15.98	10.32	14.87	6.18
Cort. (immediate post-test)	16.14	8.37	16.34	7.51
Cort. (10 min post-test)	14.96	7.57	15.67	7.37
Cort. (20 min post-test)	14.40	7.08	15.39	6.93

Note. StateChange = state anxiety change score; Cort. = cortisol levels (µg/dl); multiplied by 100. The possible range of scores for each variable is as follows: Trait test anxiety: 20 to 80, State anxiety: 20 to 60, StateChange: -40 to 40, all accuracy variables: 0 to 32.

[a] Trait test anxiety was measured only once in the first experimental session.

Table 2

Parameter Estimates from the Equality-Constrained Latent Growth Models of Cortisol

	Accuracy		Efficiency	
	Low Situational Stress	High Situational Stress	Low Situational Stress	High Situational Stress
Means				
Intercept	1.36 [0.65, 2.07]	1.71 [0.83, 2.58]	1.36 [0.65, 2.07]	1.69 [0.82, 2.57]
Slope	0.26 [-0.22, 0.74]	-0.22 [-1.10, 0.66]	0.26 [-0.22, 0.76]	-0.20 [-1.07, 0.67]
Variances				
Intercept	0.66 [0.51, 0.81]	0.88 [0.76, 0.98]	0.66 [0.51, 0.81]	0.87 [0.76, 0.98]
Slope	0.81 [0.65, 0.96]	0.99 [0.98, 1.01]	0.80 [0.64, 0.96]	0.99 [0.98, 1.01]
Model fit	$\chi^2(64) = 105.93$, $p < .01$		$\chi^2(64) = 88.31$, $p < .05$	
CFI	.95		.97	
RMSEA	.07		.05	
SRMR	.10		.10	

Note. Parameter estimates are standardized values with 95% confidence intervals presented in brackets. CFI = comparative fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual.

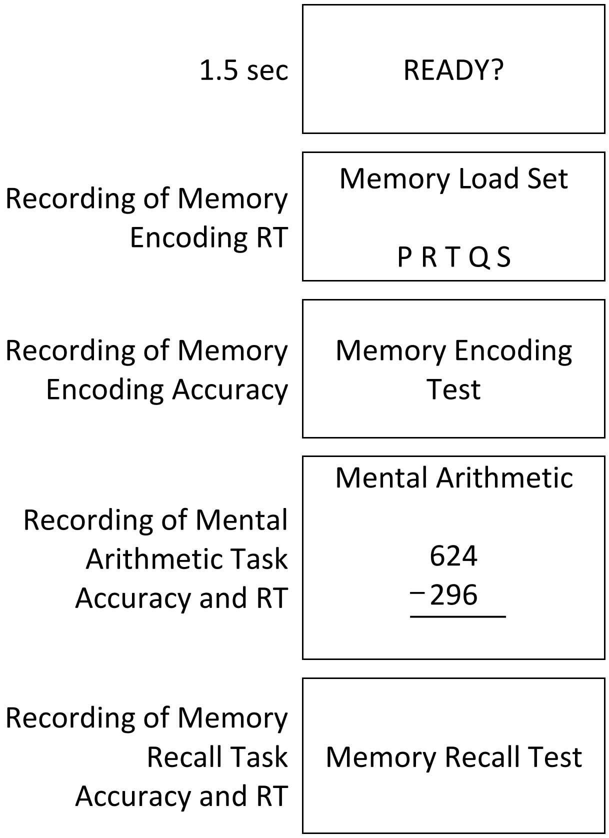

Figure 1. Sequence of events for the experimental task. RT = response time. Mental arithmetic RT was defined as the time taken to perform three mouse clicks. Memory encoding and recall RT were derived as the time taken to perform five key presses.

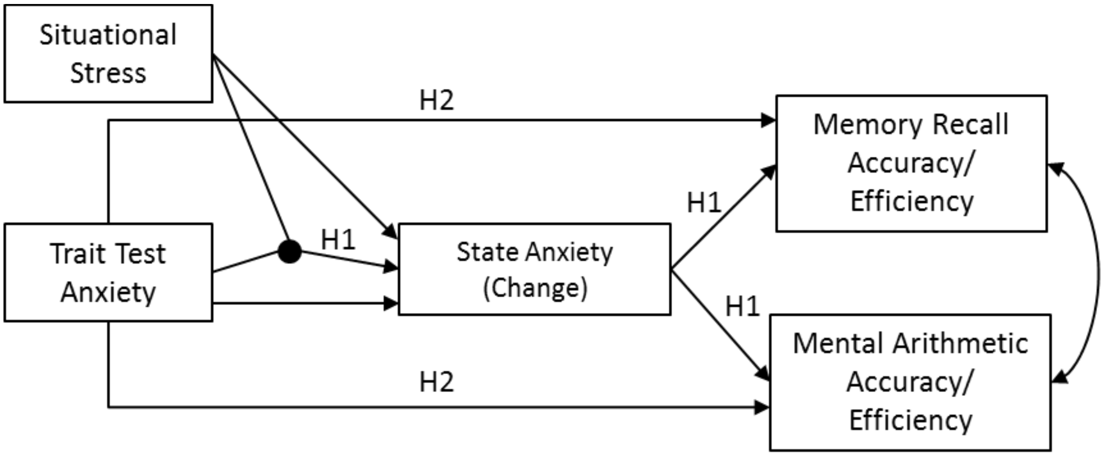

Figure 2. Hypothesized path models for accuracy and efficiency. Situational stress was a bivariate dummy variable that corresponded to the low (coded as 0) versus high situational stress condition (coded as 1). The interaction term (trait test anxiety x situational stress) is represented by two lines joining the corresponding main effects and a dot. H1 = Hypothesis 1; H2 = Hypothesis 2.

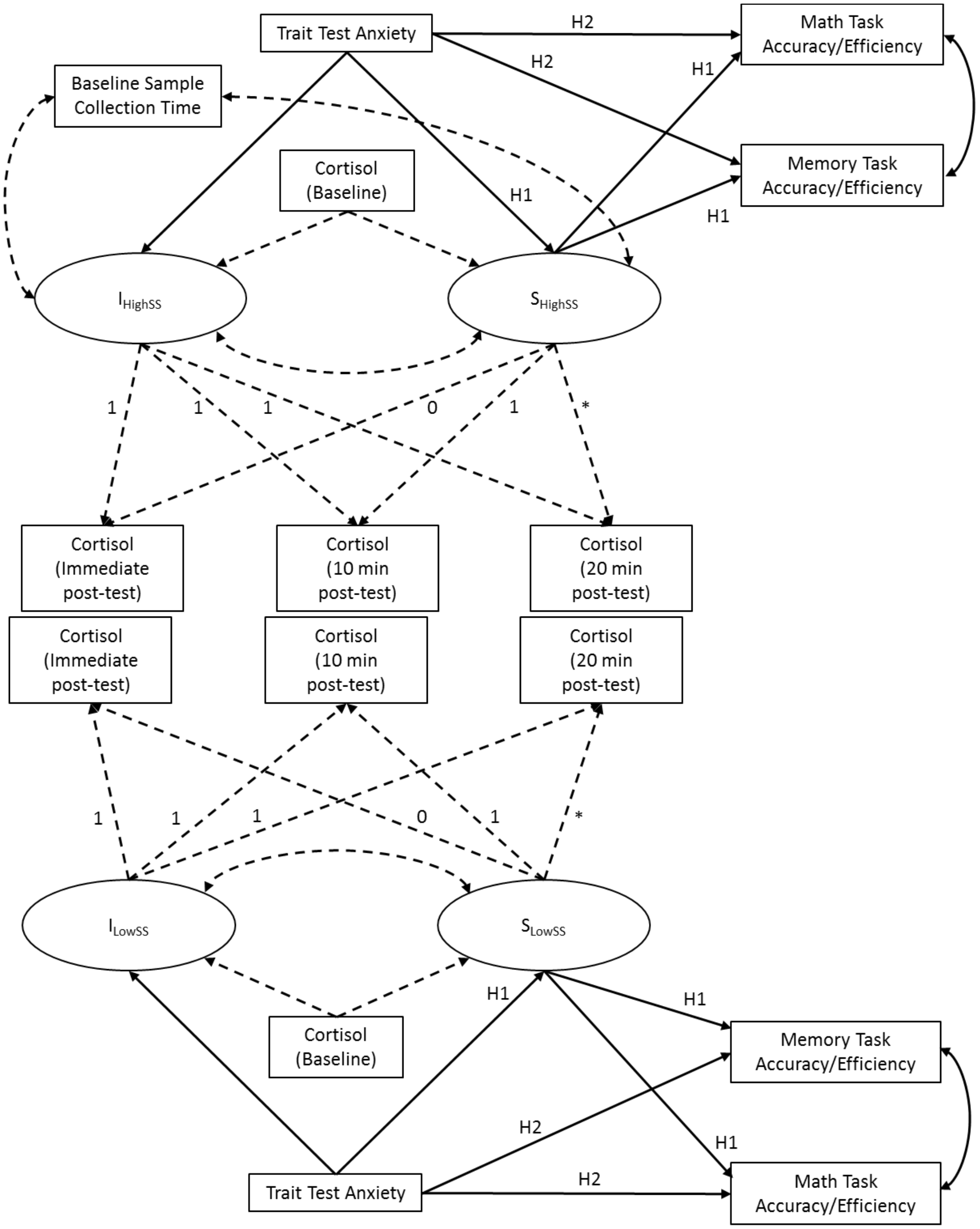

Figure 3. Latent growth curve models for high and low situational stress conditions. Paths with dotted lines constitute the growth curve models. Paths with solid lines indicate the hypothesized relations between trait test anxiety and the growth terms with mental arithmetic and memory recall performance. Residual variances are not shown. I = intercept; S = slope; HighSS = high situational stress condition; LowSS = low situational stress condition. H1 = Hypothesis 1; H2 = Hypothesis 2.

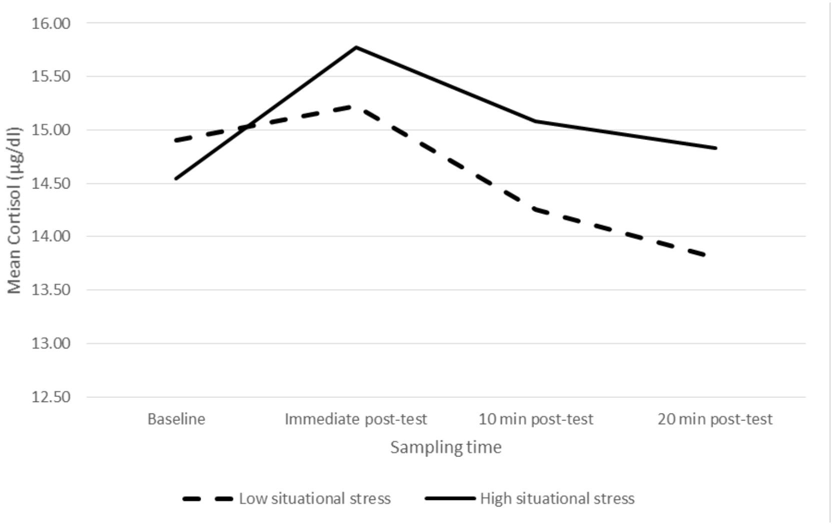

Figure 4. Mean trajectory of raw cortisol data at low and high situational stress conditions.

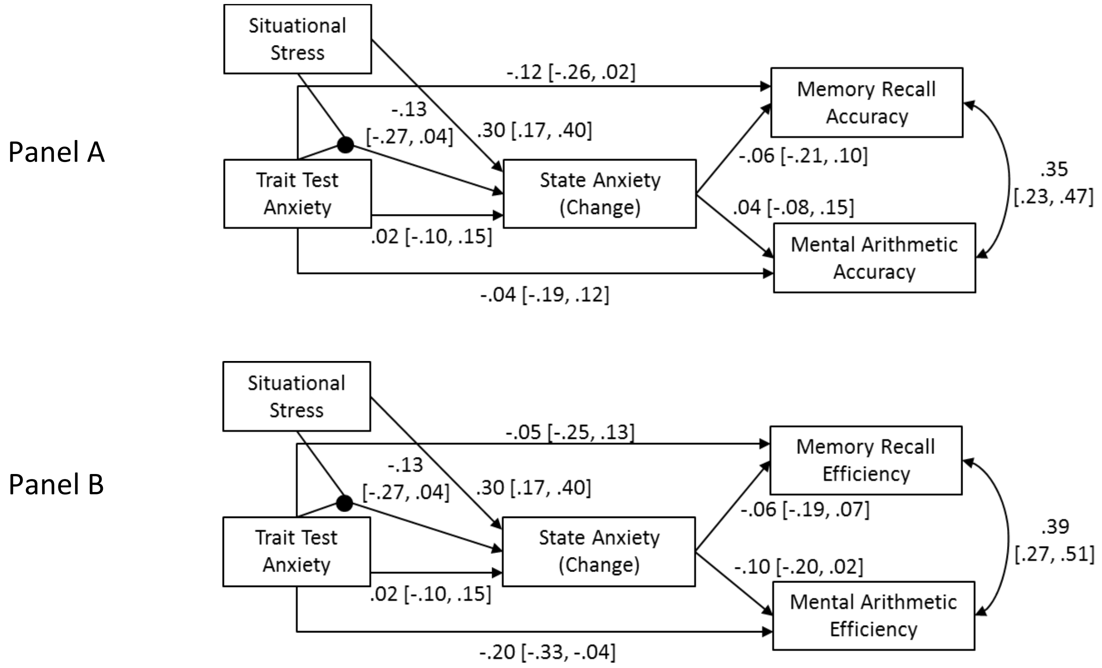

Figure 5. Path models showing standardized path coefficients and bootstrapped 95% confidence intervals (in brackets) for measures of accuracy (Panel A) and efficiency (Panel B). Situational stress was coded as 0 = low situational stress condition, 1 = high situational stress condition.