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Perception and Performance of Working Memory: Insights into Test Anxiety

Rebecca Grossman
University of Windsor

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By

Rebecca Grossman

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by

Rebecca Grossman

APPROVED BY:

E. Kustra
Faculty of Education

A. Baird
Department of Psychology

D. Jackson, Advisor
Department of Psychology

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ABSTRACT

Test anxiety is a common phenomenon that can be detrimental to cognitive performance, academic achievement, and mental health. One mechanism consistently identified as playing a role in such deficits is working memory. While many studies have investigated the relationship between working memory and test anxiety, approaches to measuring working memory have varied between using assorted standardized behavioural measures and self-report inventories. While self-report inventories are often found to be valid, there is some evidence suggesting that subjective appraisal of functioning might not be accurate in all contexts. Therefore, the purpose of this study was to determine whether self-appraisal of working memory predicted test anxiety over performance on working memory behavioural tasks, and whether prediction of test anxiety would vary as a function of both working memory self-appraisal and performance. Self-appraisal of working memory was found to be predictive of test anxiety over behavioural performance, as performance was not a significant predictor of test anxiety. The interaction between self-appraisal and performance was not found to significantly predict test anxiety. Results of this study may underscore the necessity to continue to clarify the relationship between test anxiety and different modalities of working memory assessment, as it has relevance for both the field of test anxiety research and application in clinical and educational settings. Future studies in this area may contribute to the development of interventions to support student academic success and general well-being.

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CHAPTER 1

Introduction

Test Anxiety

Test anxiety is conceptualized as the anxiety surrounding performance in evaluative situations (Putwain, 2008). While some level of test anxiety is very prevalent in student populations, the prevalence of high and debilitating levels of test anxiety has been estimated as between 15% and 22% of individuals (Putwain & Daly, 2014; Thomas, Cassady, & Finch, 2018). Test anxiety has been found to be related to many negative variables such as poor coping strategies and behaviors, poor academic performance and achievement, and low self-esteem (von der Embse, Jester, Roy, & Post, 2017).

The current edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) defines a mental disorder as a syndrome characterized by clinically significant distress, dysfunction, and disturbance in functioning (American Psychiatric Association, 2013). Although there has been work to quantify the level of test anxiety meeting the criteria of clinical significance using various inventories, test anxiety is not a discrete diagnosis in the DSM-5 (Herzer, Wendt, & Hamm, 2015; Thomas et al., 2018). Rather, test anxiety reaching clinical levels may be specified within a diagnosis of Social Anxiety Disorder, which encompasses fear of situations involving performing (American Psychiatric Association, 2013; Bögels et al., 2010).

History of Test Anxiety Research and Models

Early studies of emotion and performance formed the basis for test anxiety research (von der Embse et al., 2017). Yerkes and Dodson's (1908) animal experiments on the relationship between stimulus strength and habit formation found a pattern of optimal arousal for performance. This pattern, which eventually was referred to as the Yerkes-Dodson Law, posits that performance increases up to an optimal point of physical or mental arousal, but decreases as arousal is elevated beyond this point in an inverted U-shaped function (Robinson, 2018).

Early research on the relationship specifically between anxiety and test performance was focused on test performance within the psychometric context. Findings suggested that clinical levels of anxiety could interfere with performance on standardized intelligence tests, such as the Stanford-Binet and Wechsler Adult Intelligence Scale (WAIS), which in turn could confound the interpretation of the results (Jewett & Blanchard, 1922; Welch & Rennie, 1951). Additional research found that elevated anxiety was similarly associated with lowered scores in non-clinical populations (S. Sarason & Mandler, 1952).

In order to explain this phenomenon, Mandler and S. Sarason (1952) rooted findings in drive theory. They hypothesized that a testing situation evokes both task-directed drives and anxiety drives, stimulating opposing behaviours of task relevant effort to complete the task and reduce anxiety (facilitating anxiety), and self-centered task-irrelevant feelings of inadequacy impairing performance (debilitating anxiety). Later, this theory and its derivatives became known as the interference model of test anxiety, which sought to explain impaired performance by identifying factors disrupting information processing during testing situations (von der Embse et al., 2017). Using a cognitive approach, Liebert and Morris (1967) identified the main interfering components of test anxiety as cognitive worry over one's performance and emotionality (physical reactions to test situation). Others explained this interference using attentional theory, proposing test anxiety as dividing attention between task-relevant and irrelevant concerns leaving less attentional resources devoted to performance (Hembree, 1988).

Notably, in early literature, studies of the impact of test anxiety on cognitive performance was often conducted by psychologists within the educational context, with the authors suggesting that conclusions may be extrapolated to concerns within the educational setting (Welch & Rennie, 1951). Some early educational research noted a connection between anxiety and lower achievement, but little attention was devoted specifically to integrating test anxiety findings with educational research (Taylor, 1964). Later studies, hoping to develop interventions that could be applied in school settings, proposed expanded models that included additional dimensions to the development, maintenance, and experience of test anxiety (Tobias, 1979, 1985).

A competing model, termed the deficits model of test anxiety, was proposed in response to the interference model. Hoping to expand into educational factors, theorists conceptualized test anxiety as being due to deficits in knowledge and skills needed to perform in testing situations such as study skills, self-efficacy, motivation, and strategies for testing. In this model rooted in behavioural theory, awareness of deficits at different stages of knowledge acquisition or difficulties in past performance leads to test anxiety (Hembree, 1988; Tobias, 1985).

The deficit model was disputed following advancements in test anxiety treatment research. Hembree's (1988) meta-analysis included information from 137 treatment studies and concluded that while behavioural and cognitive-behavioural treatments (reflective of the interference model) were found to be effective at reducing test anxiety, treatments centering around study and test tasking skills (reflective of the deficit model) did not reduce test anxiety. Importantly, the behavioural and cognitive-behavioural treatments were related to improved test performance and overall academic achievement, while skill-based treatments were not related to improved performance outcomes, leading the author to conclude that test anxiety interferes with performance, supporting the interference model.

The debate between the interference and deficit models still appears in recent literature without definitive resolution, although many now recognize that the construct is more complex (Hopko, Crittendon, Grant, & Wilson, 2005; Sommer & Arendasy, 2014; von der Embse et al., 2017). Recent models conceptualize test anxiety as being multi-dimensional, integrating previous models to better understand the complexities of the process of developing and experiencing test anxiety. The transactional model suggests that coping with stressful situations (testing) is a result of both personal traits (such as personality) and appraisals of threat of the situation (von der Embse et al., 2017). An extension of this model, the self-referent executive processing model of test anxiety (S-REF), theorizes that test anxiety is a result of dynamic interaction between three systems: executive regulatory processes (such as emotion regulation), self-beliefs (such as control), and maladaptive situational interactions (such as self-handicapping). The S-REF models how these components form the process leading to and maintaining test anxiety (Putwain, 2018).

Other contemporary models attempt to capture many different facets and components of test anxiety. The cognitive-behavioural model proposes that test anxiety is the result of interaction of cognitive processes and perceptions, learning experiences, demographic characteristics, social and cultural context, and environmental factors (Segool, von der Embse, Mata, & Gallant, 2014). The biopsychosocial model of test anxiety captures the biological and psychological vulnerabilities within an individual that interact with the social or educational context leading to test anxiety. It includes components such as cognitive interference, physiological hyperarousal, social concerns, task irrelevant behaviours, worry, and facilitating anxiety; components that arise from an individual's interaction and perception of their internal state, others, and their environment (Lowe, 2018; Lowe et al., 2008).

Test Anxiety and Cognitive Performance

Standardized tests of cognitive and neuropsychological abilities are used to determine functioning across a range of domains, and may be able to diagnose dysfunction and find abnormalities in a non-invasive manner. Assessment is used in many different contexts including clinical, educational and forensic settings, and can play a role in producing outcomes that may have a large impact on an individual's life (Lezak, Howieson, Bigler, & Tranel, 2012). As conclusions drawn from psychological testing rely on the assumption that results accurately reflect true cognitive ability, research has identified different factors that may interfere with the validity of the results of testing (Larrabee, 2011).

The interference of test anxiety on cognitive performance has been the subject of much study. After noting this relationship across 66 studies, Hembree's meta-analysis (1988) analyzing studies from the 1950s to 1980s noted the resulting bias caused by anxiety at both the individual and systematic level of testing. As scores from test anxious individuals could be considered undervalued and test anxiety was a prevalent phenomenon, average scores used for normative purposes might not be accurate. This led to the author challenging the validity of the entire testing process.

Although it has been well established that overall performance on standardized measures such as the WAIS is impacted by test anxiety, findings suggest differential impact of anxiety on specific abilities or skill sets. On the WAIS alone, test anxiety has been found to be related to lower scores on the different indexes of ability (Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed) but not consistently (Gass & Curiel, 2011; Gass & Gutierrez, 2017; Hopko et al., 2005; Ng & Lee, 2015). This may be due to methodological constraints, particularly the researchers' conceptualization of test anxiety and resulting choice of test anxiety measure (Hopko et al., 2005; von der Embse et al., 2017).

One focus of a recent meta-analysis by von der Embse and colleagues (2017) was to compile findings accounting for methodological differences in conceptualization of test anxiety. They included 19 studies that examined the relationship between test anxiety and performance on intelligence tests. They found correlations between self-report measures of test anxiety and scores on verbal abilities (vocabulary and comprehension skills) as well as on measures of cognitive proficiency abilities (working memory and processing speed scores). They also found a smaller relationship between test anxiety and nonverbal reasoning abilities (fluid reasoning, problem solving, and visual processing). Further, they attempted to analyze personal components of test anxiety correlated with performance deficits commonly recognized in the literature including cognitive (worry, test-irrelevant thoughts, cognitive obstruction), affective/physiological (autonomic reactions, tension, emotionality), behavioural (off-task behaviours), and social (social derogation) components. However, as many studies did not differentiate between or include all factors, they only had sufficient data to examine the cognitive and affective/physiological components of test anxiety, which were both correlated with FSIQ score.

Of note, while many studies do not imply causality or focus on the interference of test anxiety on cognitive performance, some have hypothesized that this relationship is directional, fitting with the deficit model of test anxiety. Based on findings, some have concluded that deficits in cognitive skills are at the basis of higher test anxiety accounting for poor performance, in both those with diagnosed learning disabilities and in a typically functioning population (Nelson, Lindstrom, & Foels, 2013; O'Donnell, 2017; Sommer & Arendasy, 2014).

The Effects of Test Anxiety on Education

As school-related anxiety is common among students, the prevalence of clinical or debilitating levels of test anxiety is also relatively high, and has been estimated at between 15% and 22% of individuals (Putwain & Daly, 2014; Thomas et al., 2018). The relationship between academic outcome factors and test anxiety has been well established; test anxiety has consistently been found to be related to low self-esteem, difficulty with learning and engagement, poor coping strategies and behaviors, poor test performance, lower grades, and lower overall academic achievement (Hembree, 1988; Seipp, 2007; von der Embse et al., 2017). Further, those with elevated levels of test anxiety have been found to be at increased risk of developing depression and generalized anxiety disorder (Leadbeater, Thompson, & Gruppuso, 2012). Similar to concerns regarding the validity of cognitive performance measures, some authors have concluded that academic scores from test anxious individuals should be considered undervalued (Hembree, 1988).

McDonald (2001) found that test anxiety was on the rise among students throughout primary and secondary education. This is likely due to changes in the nature of testing in schools, with certain countries using increased amounts of "high-stakes" exams. "High-stakes" exams include standardized measures with serious consequences such as entrance exams (such as the SAT/ACT, the GRE) and state exams (used to determine academic progress in individual students as well as teacher and school efficacy). As expected, “high-stakes” exams have been found to be associated with higher levels of test anxiety than a regular classroom exam (Segool, Carlson, Goforth, von der Embse, & Barterian, 2013; Segool et al., 2014).

Personal and Demographic Correlates of Test Anxiety

Personal Factors. Results of two separate meta-analyses – Hembree’s published in 1988 and von der Embse and colleagues’ published in 2017 – found various intrapersonal factors related with test anxiety. One category of personal variable analyzed was self-concept, which included subcategories of self-esteem (judgment of past successes or failures relative to desired outcome), self-efficacy (belief in ability to engage in behaviours facilitating academic success), locus of control (belief of personal control over academic tasks), academic confidence (belief in ability to adequately perform academic tasks), and self-regulation (monitoring learning outcomes and applying necessary strategies). The findings of both meta-analyses were consistent, in that all aspects of self-concept studied were negatively correlated with test anxiety, with self-esteem and self-efficacy sharing the strongest negative relationship. The authors concluded that these results suggested that students with higher test anxiety were likely to have negative beliefs in themselves and their ability to succeed on academic tasks. (Hembree, 1988; von der Embse et al., 2017).

von der Embse and colleagues (2017) also examined motivation, goal orientation, and coping strategies. They found that test anxiety was negatively related to intrinsic, but positively associated with extrinsic motivation. That is, individuals motivated by external demands rather than internal standards were more likely to have higher levels of test anxiety. Similarly, achievement goals were also examined. Mastery-avoidance goals (desire to develop knowledge to avoid incompetence on a task) and performance-avoidance (desire to avoid performing worse relative to others) were both positively correlated with test anxiety. The authors interpreted this to mean that those with higher test anxiety were more likely to have an avoidance goal orientation. Further, to study the relationship between test anxiety and coping strategies, they analyzed avoidance coping (engaging in non-relevant cognitions or behaivours to avoid a stressful situation) and problem focused coping (manage stress by solving the problem). Results suggested that those with higher test anxiety were more likely to avoid stressors as a coping strategy.

Finally, studies examining the relationship between test anxiety and "Big Five" personality factors were also analyzed in von der Embse and colleagues' (2017) meta-analysis. The authors found a positive correlation between test anxiety and Neuroticism, a factor that has often been found to be related to general anxiety, depression, and vulnerability to environmental stressors. They also found that test anxiety had a small negative relationship with Conscientiousness, a factor which has been found to be related to personal variables such as intrinsic motivation and self-efficacy, which share a negative relationship with test anxiety (von der Embse et al., 2017).

Demographic factors. The relationship between test anxiety and demographic variables has been analyzed. Meta-analytic findings suggest that those with a school-related disability diagnosis, such as attention deficit hyperactivity disorder or specific learning disability, had higher levels of test anxiety. Results also suggested that more females reported test anxiety than males, and that students identifying as a minority ethnicity reported higher levels of anxiety. However, both demographic relationships with test anxiety were found to decrease as students progressed through grade level, and have decreased in strength throughout the history of test anxiety research (Hembree, 1988; von der Embse et al., 2017).

Neurological Correlates of Test Anxiety

Research aimed at examining the mechanisms by which test anxiety leads to poor performance on cognitive tasks has suggested that it may be due to activation of the "fight or flight complex" and the sympathetic nervous system, similar to other forms of anxiety (Bishop, 2007). Studies have found various physiological markers specifically related to activation of this system by test anxiety, such as increased levels of cortisol (Clutter, Potter, Alarbi, & Caruso, 2017; Leininger & Skeel, 2012), higher salivary pH levels (Cohen & Khalaila, 2014), and increased heart rate and blood pressure (Conley & Lehman, 2012; Delgado, Toukonen, & Wheeler, 2018).

Other mechanisms have been indirectly identified through treatment studies, including beta blockade which blocks adrenergic action in the central nervous system and the peripheral nervous system (specifically the heart) resulting in lower heart rate and blood pressure and increasing performance on cognitive tasks in individuals with test anxiety (Faigel, 1991; Müller, Mottweiler, & Bublak, 2005). Additionally, treatments targeting heart rate variability resulted in reduced test anxiety and increased test performance (McCraty & Shaffer, 2015; von der Embse, Barterian, & Segool, 2013).

Neuroimaging studies have found that the dorsolateral prefrontal cortex (DLPFC) plays an important role in the stress response and cognitive performance during testing. Acute stress (such as test anxiety in the context of a testing situation) has been found to activate the locus coeruleus, which involves the release of norepinephrine in the prefrontal cortex. Acute stress also induces the activation of the prefrontal dopamine system, causing elevations of dopamine. While some catecholamine (norepinephrine and dopamine) release is necessary for optimal activation of the DLPFC, excessive elevation reduces activation of the DLPFC. This reduction of activity allows for the reallocation of neural resources away from the frontoparietal executive network to the default mode network, impairing higher-order cognitive skills such as attention and working memory. With this pattern of activation, performing a working memory task while under stress (like test anxiety in a testing context) may be considered a type of dual processing, as anxiety increases attention to threat-related stimuli of negative thoughts regarding performance. The inhibition of anxiety-related irrelevant thoughts becomes another task depleting cognitive resources, making completing the primary task more difficult (Arnsten & Li, 2005; Eysenck, Derakshan, Santos, & Calvo, 2007; Gore, Skudlarski, Hampson, Constable, & Driesen, 2006; Qin, Hermans, van Marle, Luo, & Fernández, 2009).

While not directly examining test anxiety, neuroimaging studies have also looked at the role of the amygdala in various anxiety disorders. Individuals with various clinical anxiety disorders (which includes those with test anxiety) have been found to have decreased gray matter volume of the amygdala and increased amygdala response toward negative stimuli (Strawn et al., 2015). Additionally, the amygdala may play a role in perceiving and attending to negative stimuli and the acquisition of conditioned fear responses in those with clinical anxiety disorders (Bishop, 2007). Furthermore, increased activation of the amygdala has been found in individuals with higher neuroticism, a personality factor related to test anxiety (Cunningham, Arbuckle, Jahn, Mowrer, & Abduljalil, 2010).

Working Memory and Test Anxiety

Working memory is conceptualized as a system that processes and stores a limited amount of information for a temporary amount of time before being made available for additional information processing. The working memory system contains a primary system known as the central executive, with two subsystems – the phonological loop and the visuospatial sketch pad. The function of the central executive is attention related tasks including inhibition and attentional shifting. The phonological loop sub-system is the sub-vocal rehearsal of material to maintain information while the visuospatial sketchpad is the manipulation of visual material to maintain information (Baddeley, 2003).

Test anxiety has been found to be consistently correlated with working memory; specifically, test anxiety is thought to impact the central executive system and phonological loop sub-system through inability to disengage attention from perceived threat related stimuli and resulting interfering thoughts (a component commonly referred to as worry). Off-task worry and focus, as well as compensatory strategies used to overcome deficits, reduces attentional and cognitive resources required to retrieve and apply task-related information, impacting performance (Ikeda, Iwanaga, & Senva, 1996; Mowbray, 2012).

Additional studies suggest that level of test anxiety and ability to compensate for cognitive interference may interact to cause deficits. Individuals with high test anxiety have been found to perform worse on tasks that were increasingly complex compared to those with low test anxiety. Meaning, individuals with high test anxiety have reduced compensatory ability in accordance with level of stress (Beilock, Holt, Kulp, & Carr, 2004). Even without performance deficits, individuals with high test anxiety have been found to have deficits in processing efficiency due to employing compensatory strategies, resulting in longer durations to complete a task (Eysenck, Payne, & Derakshan, 2005; Mowbray, 2012).

Working memory capacity has also been found to moderate the relationship between anxiety and performance, such that those with average working memory capacity are not as strongly impacted by anxiety, while those who generally have lower working memory capacity were more vulnerable to the detrimental interference of anxiety resulting in lower performance (Johnson & Gronlund, 2009; Owens, Stevenson, Hadwin, & Norgate, 2014). Furthermore, research has suggested that knowledge of lower working memory abilities and resulting poor performance may cause high levels of test anxiety. Nelson and colleagues (2013) suggested this interpretation based on finding that working memory ability could predict test anxiety in those with dyslexia, while O'Donnell (2017) made a similar hypothesis based on results that suggested those with greater working memory difficulties had both an earlier onset age and higher levels of test anxiety.

Objective

Many studies have investigated the relationship between working memory and test anxiety with varying approaches to measure working memory. Some studies - such as Gass and Curiels' (2011) - use standardized performance assessment measures, while others – such as O'Donnell's (2017) – use self-report inventories. While self-report inventories are often found to be valid in relation to the construct, there is some evidence suggesting that subjective cognitive appraisal might not be accurate. Importantly, certain clinical disorders, such as anxiety, depression, ADHD, and fibromyalgia directly impact objectivity of self-report, leading to over-reporting of negative symptoms and dysfunction under high-stress testing conditions (Rabbitt, Maylor, McInnes, Bent, & Moore, 1995; Steward, Tan, Delgaty, Gonzales, & Bunner, 2017; Suhr & Wei, 2013; Walitt et al., 2016). Other studies suggest that self-report inventories of executive function (which include overlapping working memory processes) are more strongly related to personal and behavioural factors than to objective cognitive performance. For example, the Behaviour Rating Inventory of Executive Function (BRIEF), was found to be more related to behavioural disruption and impairment rather than performance on executive functioning and/or working memory tasks (Mcauley, Chen, Goos, Schachar, & Crosbie, 2010). In non-clinical samples, other executive functioning inventories were correlated with neuroticism and conscientiousness personality factors without being significantly correlated to performance on behavioural measures (Buchanan, 2016; Gerstorf, Siedlecki, Tucker-Drob, & Salthouse, 2008). Moreover, neuroimaging studies have found that the different types of measures do not assess the same activation patterns and functions in the brain (Faridi et al., 2015).

Therefore, the purpose of the present study was to examine the relationship between self-appraisal and performance-based behavioural assessment of working memory in the context of test anxiety. To achieve this objective, self-reported working memory was compared with scores on working memory behavioural assessments and evaluated in relation to predicting test anxiety. It was hypothesized that a discrepancy between self-reported and behavioural measures of working memory would be predictive of higher test anxiety, meaning individuals with higher test anxiety would report more working memory difficulty than found in performance. It was also hypothesized that test anxiety would vary as a function of the combination of objective and subjective working memory; that the discrepancy between self-reported difficulties and behavioural measures of working memory would be larger for those with high levels of test anxiety compared with individuals with average and lower test anxiety.

CHAPTER 2

Methods

Participants

Following ethics approval from University of Windsor's Research Ethics Board, participants for this study were recruited from the University of Windsor Psychology Participant Pool of undergraduate students. Participants were required to be 18 years of age or older, and endorse both being fluent in English and having a device with the technological specifications to listen to audio in order to participate (see Appendix A for Participant Pool advertisement). The participants received course credit for their involvement.

A power analysis was conducted using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2013) to determine the number of participants required to detect a relationship between test anxiety, self-reported measures, and behaviourally based measures of working memory. The following parameters were set for a Linear multiple regression: Fixed model, R^2 increase" F test: Alpha level = .05; Power = .95; Effect size (Cohen's *d*) = .15; Number of predictors = 4. Based on these parameters, the estimated sample size required was 119 participants. 197 participants were recruited for the study.

As the questionnaires and behavioural working memory task components were in English, participants were required to be fluent in English. They were also required to have the technical capabilities to play audio clips for the digit span task. Participating students had a mean age of 21.25 (SD = 4.25) and were equally distributed between 1st, 2nd, 3rd, and 4th years of university. After ensuring that all self-reported cumulative averages were on the same scale by converting any 4.0 scale answers into percentages out of 100, mean cumulative average was 78.66 (SD = 9.03). Just over a third of participants (38.5%) reported experiencing current symptoms of mood disorder, which included severe anxiety (28%), depression (22.4%), and manic symptoms (0.6%).

Ten participants (6.6%) reported being diagnosed with either ADHD or a learning disorder. When comparing scores on the measures of interest and digit span performance, these individuals did not score significantly different than the remaining participants and were therefore retained for the analysis.

Participants who reported being diagnosed with a neurological condition such as epilepsy or stroke, and those currently experiencing symptoms of traumatic brain injury were excluded from the analysis (three participants). At the end of the study, students were asked to report the amount of effort given to both the survey and the task. Seven participants who indicated the lowest amount of effort ('no effort') were excluded from the analysis. An additional 17 participants did not complete any of the inventories or the digit span task, while six did not complete the digit span task. After excluding these participants, 161 cases were retained for analysis.

Procedure

The study was completed online through Qualtrics software. Participants were instructed to ensure that they had adequate time, as well as appropriate equipment and/or setting (a computer with speakers in private or headphones in public) to complete the surveys and task. After obtaining informed consent, the participants completed a questionnaire requesting basic demographic variables as well as a basic history of psychiatric and psychological functioning. The consent, demographic, and history component required about ten minutes to complete. Subsequently, participants completed self-report measures of different aspects of test anxiety as well as a self-report measure of executive functioning (~30 minutes).

After completing the questionnaire, participants continued to a digit span task – the behavioural working memory task. The participants were instructed to complete a brief audio task to ensure adequate audio capabilities and settings prior to beginning the task. Participants then completed the digit span task, which took ten minutes to complete. Before completing the study, participants were provided with debriefing information. The entire session took around one hour to complete.

Measures

Demographics and history. The initial questionnaire collected basic demographic variables such as age, academic year, and languages spoken. It also gathered data on current psychological and psychiatric functioning through self-report measures (see Appendix B). Gender and ethnicity variables were not collected, as differences have been found to be reduced in university students (von der Embse et al., 2017).

Test anxiety measures.

Cognitive Test Anxiety Scale – Second Edition (CTAS). The CTAS is a 24-item scale measuring cognitive indicators of test anxiety. Respondents were instructed to rate the degree to which items were descriptive of themselves using a

4-point Likert scale ranging from *not at all like me* (1) to *very much like me* (4). Scale items consisted of statements such as “I tend to freeze up on things like intelligence tests and final exams” and “At the beginning of a test, I am so nervous that I often can't think straight”. The CTAS has been found to have high internal consistency (Cronbach’s α=.96), and has been found to validly assess cognitive test anxiety in culturally diverse settings (Cassady & Johnson, 2002; Thomas et al., 2018). See Table 1 for scale descriptive and alpha coefficients for all measures used in this study.

Table 1

Descriptive Statistics of Scales and Scale Items

Scale	*N*	*M* (SD)	Range	α
CTAS	154	2.40 (0.69)	1.08 - 3.92	0.96
TAI	154	2.44 (0.76)	1.05 - 4.00	0.96
STAI-T	154	2.43 (0.56)	1.00 - 3.85	0.94
CFQ	154	2.87 (0.67)	1.36 - 4.60	0.93

Note. N = number of participants; CTAS = Cognitive Test Anxiety Scale; TAI = Test Anxiety Inventory; STAI-T = State-Trait Anxiety Inventory - Trait; CFQ = Cognitive Failures Questionnaire.

Test Anxiety Inventory (TAI). The TAI consists of 20 statements of possible test-taking experiences or thoughts such as “During tests I feel very tense,” and “I seem to defeat myself while working on important tests.” Items are ranked on a 4-point Likert scale ranging from *almost never* (1) to *almost always* (4). The TAI is commonly used for measuring test anxiety and has been shown to be internally consistent (α = .95) and valid (Spielberger, 1980; Szafranski, Barrera, & Norton, 2012).

State-Trait Anxiety Inventory (STAI-S and STAIS-T). The STAI is a measure used to assess an individual's general anxiety levels (trait, or STAI-T) as well as current intensity of anxiety (state, or STAI-S). The Trait component contains 20 statements such as "I lack self-confidence" and "I am a steady person". Respondents were instructed to rate how they generally feel on a 4-point Likert scale ranging from *almost never* (1) to *almost always* (4). The State component contains 20 statements such as "I feel at ease" and "I feel upset". Respondents were instructed to rate how they felt at the current moment on a 4-point Likert scale ranging from *not at all* (1) to *very much so* (4). The STAI is commonly used for measuring state and trait anxiety and has been shown to be internally consistent ($\alpha = .90$) and valid (Spielberger, Gorsuch, & Lushene, 1970).

Self-reported working memory.

The Cognitive Failures Questionnaire (CFQ). The CFQ is a 25-item questionnaire measuring tendency to make common cognitive mistakes. Items were presented along a 5-point Likert scale, where frequency of occurrences are rated in frequency from *never* (0) to *very often* (4). Scale items include questions such as "Do you find you forget what you came to the shops to buy?" and "Do you read something and find you haven't been thinking about it and must read it again?". Updated studies describing the psychometric properties of the measure reported it had high internal consistency (Cronbach's α=.92), supporting data from this scale as reliable (Bridger, Johnsen, & Brasher, 2013). The scale has been found to demonstrate convergent, discriminant, and construct validity, supporting the use of the scale for the purposes of assessing executive function (including working memory) in the proposed study (Broadbent, Cooper, FitzGerald, & Parkes, 1982; Carrigan & Barkus, 2016).

Behavioural assessment of working memory.

Digit span task. The digit span task is a behavioural assessment of working memory ability, included in common standardized measures of cognitive functioning, such as the WAIS-IV and the WISC-V. During this task, participants were required to recall increasingly longer strings of digits in the order presented (forward) or in reverse order (backward). Digit span performance is considered to have good construct validity and an important indicator of cognitive and intellectual functioning (Benson, Hulac, & Kranzler, 2010; Gignac & Weiss, 2015; Wechsler, 2008).

The specific digit span task used in this study was completed within the Qualtrics software. During the forward portion of the task, the participants were instructed to play an audio clip, remember a sequence of digits, then type the digits in a box on the subsequent page. Participants were informed that the page with the audio clip of the digit sequence would automatically advance after a set amount of time, preventing them from playing the clip multiple times and/or recording the span. Forward sequences were presented at a rate of one digit per second, and ranged from two to nine digits. Sixteen sequences were presented in ascending order, with each length of digit string getting two trials.

The backwards portion of the task followed similar procedures, with participants playing an audio clip and typing digits in a box on a subsequent page, however, participants were instructed to reverse the digits presented to them in the sequence. Backwards sequences ranged from two to eight digits, resulting in 14 sequences with each length of digit string getting two trials.

The forwards and backwards portion of the task were scored by summing the number of digit strings recalled correctly before meeting a discontinue rule. A discontinue was obtained by a participant failing to recall both strings in a set, meaning failing to recall both trials of a string length. The forwards and backwards scores were summed together to yield a total score. See Table 2 for descriptive statistics of the digit span task.

Table 2

Descriptive Statistics of Digit Span Responses

Task	*N*	*M* (SD)	Range
Forward	154	8.89 (4.00)	0 - 16
Backward	154	7.28 (3.77)	0 - 14
Total Score	154	16.17 (7.22)	0 - 30

Prediction and evaluation of digit span performance. In addition to the CFQ, a formal measure of executive function and working memory, participants were asked to directly predict performance on the digit span task. Prior to the task, participants were asked to predict how many digits they would be able to recall, as well as how they predicted they would perform compared to their peers. Following the digit span task, participants were asked to rate their perception of their performance compared to peers.

CHAPTER 3

Results

Prior to analysis, inventory responses were examined through various SPSS programs for accuracy of data entry, missing values, and fit between their distributions and the assumptions of regression analysis.

Of the 161 participants who completed the study and were retained for analysis, 19 cases (11.8%) contained at least one missing data point. Of the variables used in the analyses, 30 (32.3%) contained a missing data point. For these 30 variables, each variable had less than 2% missing. Overall, 0.25% of possible data points (or 37 data points) were missing. The average amount of missing data per incomplete case was 2.12%. While Little's MCAR test revealed that data was not missing completely at random, no patterns of missing data were observed. Missing values were then imputed using expectation maximization.

In order to evaluate whether self-appraisal of working memory predicted test anxiety over performance on working memory behavioural tasks, two three-stage hierarchical multiple regression analyses were performed with the test anxiety measures as the dependent variable. The first multiple regression analysis used the CTAS as the dependent variable, while the second included the TAI as the dependent variable. For both analyses, trait anxiety (STAI-T score) and digit span performance were entered in the first block, as they were expected to be predictors of test anxiety. The CFQ was entered in the second, and prediction about performance was entered in the third stage in order to evaluate whether adding these variables explained additional variance when predicting test anxiety.

Results of evaluation of assumptions indicated that seven cases were multivariate outliers and were removed from the analyses leaving 154 cases. The assumptions of normality, linearity, homoscedasticity, independence of errors, lack of multicollinearity and singularity were within acceptable limits. Table 3 provides a correlation matrix describing the zero order relationships between the independent predictor variables and both dependent variables.

Table 3

Correlations Among Variables

Variable	1	2	3	4	5
1. CTAS	–				
2. TAI	0.92**	–			
3. STAI-T	0.61**	0.63**	–		
4. DS Score	0.09	0.11	0.03	–	
5. CFQ	0.66**	0.63**	0.61**	0.002	–
6. DS Prediction	0.21*	0.18	0.33**	0.12	0.36**

Note. *p<.05, **P<.001; CTAS = Cognitive Test Anxiety Scale; TAI = Test Anxiety Inventory; STAI-T = State-Trait Anxiety Inventory - Trait; DS Score = Digit span score; CFQ = Cognitive Failures Questionnaire; DS Prediction = Digit span prediction.

The first hierarchical multiple regression analysis used the CTAS as the dependent variable. Table 4 displays the correlations between the variables, the unstandardized regression coefficients (*b)* and intercept, the standardized regression coefficients (β), the partial correlations (pr^2), and semi-partial correlations (sr^2), and R, R^2, and adjusted R^2 for each block of independent variables. At the first stage, R for regression was significantly different from zero,

$F(2, 151) = 42.85$, $p < .001$, $R^2 = .36$. The adjusted R^2 value of .35 indicated that 35% of the variability in test anxiety, as measured by the CTAS, was predicted by the combination of trait anxiety and digit span performance. However, while the regression coefficient for trait anxiety was significant, digit span performance was not, indicating that digit span performance did not contribute significantly to the regression. Introducing the CFQ measure to the regression model in the second block accounted for an additional 11.2% of the variance, and resulted in significant change to R^2, $F(1, 150) = 32.1$, $p < .001$, $R^2 = .48$. The addition of prediction of digit span performance in the final block did not result in significant change. This pattern of results suggests that over a third of the variability in test anxiety is predicted by trait anxiety, although when CFQ is introduced into the model, CFQ becomes a slightly stronger predictor of test anxiety than trait anxiety. Both digit span performance and prediction of digit span performance add no further prediction.

Table 4

Hierarchical Regression of Variables Predicting Cognitive Test Anxiety

Model	Variable	*B*	*SE B*	***β***	*pr*^{2}	*sr*^{2}	*R*	R^2	ΔR^2
1	Trait Anxiety	0.73*	0.08	0.60	0.36	0.36	0.60*	0.36	0.36
	Digit Span Performance	0.003	0.006	0.03	0.002	0.001			
2	Trait Anxiety	0.41*	0.09	0.33	0.12	0.07	0.69*	0.48	0.112
	Digit Span Performance	0.002	0.006	0.02	0.001	0.0004			
	CFQ	0.44*	0.08	0.43	0.18	0.12			
3	Trait Anxiety	0.42*	0.09	0.34	0.12	0.07	0.69	0.48	0.006
	Digit Span Performance	0.002	0.006	0.03	0.002	0.001			
	CFQ	0.45*	0.08	0.44	0.18	0.12			
	Prediction of Digit Span Performance	-0.06	0.05	-0.08	0.01	0.005			

*p<.01

The second hierarchical multiple regression analysis used the TAI as the dependent variable. Table 5 displays the correlations between the variables, the unstandardized regression coefficients (*b)* and intercept*,* the standardized regression coefficients (β), the partial correlations (pr^2), and semi-partial correlations (sr^2), and R, R^2, and adjusted R^2 for each block of independent variables. At the first stage, R for regression was significantly different from zero, $F(2, 151) = 41.10$, $p < .001$, $R^2 = .35$. The adjusted R^2 value of .34 indicates that 34% of the variability in test anxiety, as measured by the TAI, was predicted by the combination of trait anxiety and digit span performance. However, similarly to the previous analysis, while the regression coefficient for trait anxiety was significant, digit span performance was not, indicating that digit span performance did not contribute significantly to the regression. Introducing the CFQ measure to the regression model in the second block accounted for an additional 8.7% of the variance, and resulted in significant change to R^2, $F(1, 150) = 23.18$, $p < .001$, $R^2 = .44$. The addition of prediction of digit span performance in the final block did not result in significant change. Like the previous analysis, this pattern of results suggests that over a third of the variability in test anxiety is predicted by trait anxiety, although when CFQ is introduced into the model, CFQ becomes a slightly stronger predictor of test anxiety than trait anxiety. Both digit span performance and prediction of digit span performance adds no further prediction.

Table 5

Hierarchical Regression of Variables Predicting Test Anxiety									
Model	Variable	*B*	*SE B*	***β***	pr^2	sr^2	*R*	R^2	ΔR^2
1	Trait Anxiety	0.80*	0.09	0.59	0.35	0.35	0.59*	0.35	0.35
	Digit Span Performance	0.004	0.007	0.04	0.003	0.002			
2	Trait Anxiety	0.48*	0.11	0.36	0.12	0.08	0.66*	0.43	0.09
	Digit Span Performance	0.004	0.007	0.04	0.003	0.002			
	CFQ	0.43*	0.09	0.38	0.14	0.08			
3	Trait Anxiety	0.50*	0.11	0.37	0.13	0.08	0.67	0.43	0.009
	Digit Span Performance	0.004	0.007	0.04	0.004	0.002			
	CFQ	0.44*	0.09	0.39	0.14	0.10			
	Prediction of Digit Span Performance	-0.08	0.05	-0.1	0.02	0.01			

*p<.01

In order to investigate the second hypothesis of whether test anxiety prediction would vary as a function of the combination of self-reported and performance based assessment of working memory, an additional two hierarchical regression analyses were performed using the CTAS and the TAI as dependent variables. In both analyses, a mean centered interaction term was created in order to test whether there was an interaction between CFQ score and digit span performance which would contribute to the prediction of test anxiety. The interaction term was then input as an independent variable into both multiple regression analyses with the previously used variables. While using both the CTAS and the TAI as the dependent variable, the interaction term was not significant, and no further analyses were performed.

CHAPTER 4

Discussion

The current study investigated the relationship between self-appraisal and behavioural assessment of working memory in the context of predicting test anxiety. It was hypothesized that a discrepancy between self-reported and behavioural measures of working memory would be predictive of higher test anxiety, or that specifically, self-appraisal of working memory difficulties would be a stronger predictor of higher test anxiety than performance on a working memory task. The results supported this hypothesis. Using both test anxiety measures, the self-reported working memory measure significantly predicted test anxiety, while the behavioural task did not significantly contribute to the prediction of test anxiety. In other words, the CFQ was a significant predictor of test anxiety, while digit span performance was not found to significantly predict test anxiety. Although self-appraisal of general working memory failures (assessed through the CFQ) was a significant predictor of test anxiety, self-appraisal of specific working memory difficulties through prediction of digit span performance did not significantly contribute to the prediction model. These findings support the hypothesis that self-report of working memory difficulty was more predictive of test anxiety over behavioural performance, as performance was not a significant predictor of test anxiety. However, the hypothesis is only supported when using a general measure of working memory difficulties (the CFQ) rather than using direct prediction of performance on the working memory task.

It was also hypothesized that test anxiety would vary as a function of self-appraisal and behavioural performance of working memory. More specifically, it was hypothesized that there would be an interaction between working memory prediction and performance demonstrating that the discrepancy between self-reported and behavioural measures of working memory would be larger for those with high levels of test anxiety compared with individuals with average and lower test anxiety. However, this hypothesis was not supported as the interaction between digit-span performance and CFQ scores was not a significant predictor of test anxiety.

The current findings are situated within a large field of research investigating the relationship between working memory and test anxiety. The current results do not support previous findings that indicate a predictive relationship between working memory behavioural performance and test anxiety (Gass & Curiel, 2011; Johnson & Gronlund, 2009; Nelson et. al., 2013; Owens et al., 2014; Sommer & Arendasy, 2014). However, they are in agreement of previous findings of a relationship between general self-appraisal of working memory difficulties and test anxiety (O'Donnell, 2017; von der Embse et al., 2017). Interpreted more generally, these results are also in agreement with findings that those higher test anxiety are more likely to have negative beliefs about their ability to succeed on tasks (Hembree, 1988; von der Embse et al., 2017).

Many authors have posited models to explain the phenomenon of test anxiety. In regards to the earlier and more simple models of test anxiety, the current findings may be interpreted as fitting within the context of the interference model of test anxiety. As findings did not demonstrate a predictive relationship between a deficit in cognitive skill and test anxiety, but rather indicated that self-appraisal of working memory was predictive, the interference model is a better fit than the deficit model of test anxiety. In regards to more contemporary multi-dimensional models, these results fit within many of the complex processes found to underly, maintain, and activate test anxiety.

Importantly, the current results are in support of previous literature that found differences between self-reported and behaviourally measured cognitive performance. Some authors have found that self-report measures of working memory are more related to factors such personality traits and behavioural impairment rather than working memory performance (Buchanan, 2016; Gerstorf, et al., 2008; Mcauley et al., 2017). Further, others have found that the different methods of measurement do not assess the same activation patterns and functions in the brain (Faridi et al., 2015). While often noted as a limitation or as an area for future study, few have directly differentiated between or focused on the differences between the assessment modalities when investigating the relationship between working memory and test anxiety (von der Embse et al., 2017). As the current study found that self-appraisal of general working memory difficulties was a significant predictor of test anxiety over both (non-significant variables of) working memory performance and direct prediction of working memory performance, concerns of conflating objective and subjective cognitive performance in general and related to the study of test anxiety are substantiated.

Taken with previous findings, the current results suggest that differentiating the different modalities in the study of the relationship between working memory and test anxiety is important in test anxiety research.

Limitations and Future Directions

There were several limitations in the current study. One such limitation is the method of measuring working memory. In this study, working memory was operationalized by using a single measure of digit span performance, limiting the results to an auditory simple span task. Further, the computerized version of the test required additional cognitive skills to complete such as language comprehension (listening to digits read in English), visual perception, and motor skills (typing). It is possible that this may have confounded the measurement of auditory working memory by employing other systems and processes.

Another limitation concerns the homogeneity of the sample recruited for the study, particularly in regards to the digit span task. As the sample was taken from the undergraduate population, digit span scores were not as normally distributed as would be expected in the general population. In turn, this restriction of range may have limited the results and applicability of the findings.

To address these limitations, future directions include using other tasks to measure working memory performance. These tasks may require more complex working memory skills (such as an N-back task) or activate additional working memory systems (such as a symbol span task). Future studies may also find it useful to employ a more precise auditory digit span task, in order to eliminate the confounds of other skills, such as typing. Finally, future research may benefit from collecting a larger and more diverse sample of participants.

Implications

It is possible that these findings may have implications in both clinical and educational settings. In both clinical and educational contexts, the awareness that individuals who endorse cognitive difficulties may be more susceptible to test anxiety may help identify individuals for intervention. This awareness may also be used to prevent development of test anxiety in at-risk individuals, by preemptively teaching positive coping skills in classrooms or clinic. It may also be possible to use the findings to guide focus of intervention, by targeting or challenging negative self-beliefs about cognitive performance in order to reduce test anxiety.

The current findings also have important implications for the field of test anxiety research. By contributing to the existing body of work indicating that self-reported and behaviourally measured working memory are not correspondingly predictive in regards to test anxiety, these findings may underscore the necessity of continuing to study both the relationship between the different assessment modalities and the different assessment modalities in relation to test anxiety. The awareness of this discrepancy may also inform methodology for future research into this construct. Avoiding conflating self-appraisal and behaviourally measured test anxiety may allow for a more complete understanding of the test anxiety phenomenon and thus greater validity and generalizability of results.

Contributions that help improve the methodology of test anxiety research may have indirect applications in clinical and educational settings by increasing understanding of the test anxiety. Future research may help identify potential biases that may arise during psychometric or educational testing. Additionally, awareness of vulnerabilities may contribute to the development of additional interventions and adaptations to support student academic success, mental health, and general well-being.

Conclusion

The current study sought to better understand the relationship between self-appraisal of working memory and working memory performance in predicting test anxiety. Findings indicated that self-report appraisal of working memory was predictive of test anxiety over working memory performance, as working memory performance was not a significant predictor of test anxiety. Findings may have application in clinical and educational contexts by identifying susceptible individuals and applying appropriate interventions. Findings also shed light on the discrepancies inherent in the different modalities of working memory measurement, and emphasize the need to continue to clarify this relationship and apply this understanding to future research. By doing so, future studies may be able to better apply research in clinical and educational settings.

REFERENCES

American Psychiatric Association. (2013). *DSM 5*. *American Journal of Psychiatry*. http://doi.org/10.1176/appi.books.9780890425596.744053

Arnsten, A. F. T., & Li, B. M. (2005). Neurobiology of executive functions: Catecholamine influences on prefrontal cortical functions. *Biological Psychiatry*. http://doi.org/10.1016/j.biopsych.2004.08.019

Baddeley, A. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*, *4*(10), 829–839. http://doi.org/10.1038/nrn1201

Beilock, S. L., Holt, L. E., Kulp, C. A., & Carr, T. H. (2004). More on the fragility of performance: Choking under pressure in mathematical problem solving. *Journal of Experimental Psychology: General*, *133*(4), 584–600. http://doi.org/10.1037/0096-3445.133.4.584

Benson, N., Hulac, D. M., & Kranzler, J. H. (2010). Independent Examination of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV): What Does the WAIS-IV Measure? *Psychological Assessment*, *22*(1), 121–130. http://doi.org/10.1037/a0017767

Bishop, S. J. (2007). Neurocognitive mechanisms of anxiety: an integrative account. *Trends in Cognitive Sciences*. http://doi.org/10.1016/j.tics.2007.05.008

Bögels, S. M., Alden, L., Beidel, D. C., Clark, L. A., Pine, D. S., Stein, M. B., & Voncken, M. (2010). Social anxiety disorder: Questions and answers for the

DSM-V. *Depression and Anxiety*. http://doi.org/10.1002/da.20670

Bradley, R. T., McCraty, R., Atkinson, M., Tomasino, D., Daugherty, A., & Arguelles, L. (2010). Emotion Self-Regulation, Psychophysiological Coherence, and Test Anxiety: Results from an Experiment Using Electrophysiological Measures. *Applied Psychophysiology and Biofeedback*, *35*(4), 261–283. http://doi.org/10.1007/s10484-010-9134-x

Bridger, R. S., Johnsen, S. Å. K., & Brasher, K. (2013). Psychometric properties of the Cognitive Failures Questionnaire. *Ergonomics*, *56*(10), 1515–1524. http://doi.org/10.1080/00140139.2013.821172

Broadbent, D. E., Cooper, P. F., FitzGerald, P., & Parkes, K. R. (1982). The cognitive failures questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology*, *21*(1), 1–16. http://doi.org/10.1111/j.2044-8260.1982.tb01421.x

Buchanan, T. (2016). Self-report measures of executive function problems correlate with personality, not performance-based executive function measures, in nonclinical samples. *Psychological Assessment*, *28*(4), 372–385. http://doi.org/10.1037/pas0000192

Carrigan, N., & Barkus, E. (2016). A systematic review of cognitive failures in daily life: Healthy populations. *Neuroscience and Biobehavioral Reviews*. http://doi.org/10.1016/j.neubiorev.2016.01.010

Cassady, J. C., & Johnson, R. E. (2002). Cognitive test anxiety and academic performance. *Contemporary Educational Psychology*, *27*(2), 270–295. http://doi.org/10.1006/ceps.2001.1094

Clutter, L. B., Potter, W. T., Alarbi, A., & Caruso, J. F. (2017). Test Anxiety and Salivary Cortisol Levels in Nursing Students. *Nurse Educator*, *42*(1), 28–32. http://doi.org/10.1097/NNE.0000000000000291

Cohen, M., & Khalaila, R. (2014). Saliva pH as a biomarker of exam stress and a predictor of exam performance. *Journal of Psychosomatic Research*, *77*(5), 420–425. http://doi.org/10.1016/j.jpsychores.2014.07.003

Conley, K. M., & Lehman, B. J. (2012). Test anxiety and cardiovascular responses to daily academic stressors. *Stress and Health*, *28*(1), 41–50. http://doi.org/10.1002/smi.1399

Cunningham, W. A., Arbuckle, N. L., Jahn, A., Mowrer, S. M., & Abduljalil, A. M. (2010). Aspects of neuroticism and the amygdala: Chronic tuning from motivational styles. *Neuropsychologia*, *48*(12), 3399–3404. http://doi.org/10.1016/j.neuropsychologia.2010.06.026

Delgado, C., Toukonen, M., & Wheeler, C. (2018). Effect of Canine Play Interventions as a Stress Reduction Strategy in College Students. *Nurse Educator*, *43*(3), 149–153. http://doi.org/10.1097/NNE.0000000000000451

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336–353. http://doi.org/10.1037/1528-3542.7.2.336

Eysenck, M. W., Payne, S., & Derakshan, N. (2005). Trait anxiety, visuospatial processing, and working memory. *Cognition and Emotion*, *19*(8), 1214–1228. http://doi.org/10.1080/02699930500260245

Faigel, H. C. (1991). The Effect of Beta Blockade on Stress-Induced Cognitive Dysfunction in Adolescents. *Clinical Pediatrics*, *30*(7), 441–445. http://doi.org/10.1177/000992289103000706

Faridi, N., Karama, S., Burgaleta, M., White, M. T., Evans, A. C., Fonov, V., … Waber, D. P. (2015). Neuroanatomical correlates of behavioral rating versus performance measures of working memory in typically developing children and adolescents. *Neuropsychology*, *29*(1), 82–91. http://doi.org/10.1037/neu0000079

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2013). G*Power 3. *Heinrich-Heine University - Institute for Experimental Psychology*.

Gass, C. S., & Curiel, R. E. (2011). Test anxiety in relation to measures of cognitive and intellectual functioning. *Archives of Clinical Neuropsychology*, *26*(5), 396–404. http://doi.org/10.1093/arclin/acr034

Gass, C. S., & Gutierrez, L. (2017). Psychological variables and Wechsler Adult Intelligence Scale-IV performance. *Applied Neuropsychology:Adult*, *24*(4), 357–363. http://doi.org/10.1080/23279095.2016.1185427

Gerstorf, D., Siedlecki, K. L., Tucker-Drob, E. M., & Salthouse, T. A. (2008). Executive dysfunctions across adulthood: Measurement properties and correlates of the DEX self-report questionnaire. *Aging, Neuropsychology, and Cognition*, *15*(4), 424–445. http://doi.org/10.1080/13825580701640374

Gignac, G. E., & Weiss, L. G. (2015). Digit Span is (mostly) related linearly to general intelligence: Every extra bit of span counts. *Psychological Assessment*, *27*(4), 1312–1323. http://doi.org/10.1037/pas0000105

Gore, J. C., Skudlarski, P., Hampson, M., Constable, R. T., & Driesen, N. R. (2006). Brain Connectivity Related to Working Memory Performance. *Journal of Neuroscience*, *26*(51), 13338–13343. http://doi.org/10.1523/jneurosci.3408-06.2006

Hembree, R. (1988). Correlates, Causes, Effects, and Treatment of Test Anxiety. *Review of Educational Research Spring*, *58*(1), 47–77.

Herzer, F., Wendt, J., & Hamm, A. O. (2015). Discriminant validity of constructs derived from the self-regulative model for evaluation anxiety for predicting clinical manifestations of test anxiety. *Behaviour Research and Therapy*, *73*, 52–57. http://doi.org/10.1016/j.brat.2015.07.012

Hopko, D. R., Crittendon, J. A., Grant, E., & Wilson, S. A. (2005). The impact of anxiety on performance IQ. *Anxiety, Stress & Coping*, *18*(1), 17–35. http://doi.org/10.1080/10615800412336436

Ikeda, M., Iwanaga, M., & Senva, H. (1996). Test Anxiety and Working Memory System. *O Perceptual and Motor Skills*, *82*, 1223–1231. http://doi.org/10.2466/pms.1996.82.3c.1223

Jewett, S., & Blanchard, P. (1922). Influence of Affective Disturbances on Response to the Stanford-Binet Test. *Mental Hygiene*, *6*, 39–56.

Johnson, D. R., & Gronlund, S. D. (2009). Individuals lower in working memory capacity are particularly vulnerable to anxiety's disruptive effect on performance. *Anxiety, Stress and Coping*, *22*(2), 201–213. http://doi.org/10.1080/10615800802291277

Larrabee, G. (Ed.). (2011). *Forensic Neuropsycholgy: A Scientific Approach* (2nd ed.). Oxford: Oxford University Press.

Leadbeater, B., Thompson, K., & Gruppuso, V. (2012). Co-occurring Trajectories of Symptoms of Anxiety, Depression, and Oppositional Defiance From Adolescence to Young Adulthood. *Journal of Clinical Child and Adolescent Psychology*, *41*(6), 719–730. http://doi.org/10.1080/15374416.2012.694608

Leininger, S., & Skeel, R. (2012). Cortisol and self-report measures of anxiety as predictors of neuropsychological performance. *Archives of Clinical Neuropsychology*, *27*(3), 318–328. http://doi.org/10.1093/arclin/acs035

Lezak, M. D., Howieson, D. B., Bigler, E. D., & Tranel, D. (2012). *Neuropsychological Assessment* (Fifth). New York: Oxford University Press.

Liebert, R. M., & Morris, L. W. (1967). Cognitive and emotional components of test anxiety: A distinction and some initial data. *Psychological Reports*, *20*(3), 975–978. http://doi.org/10.2466/pr0.1967.20.3.975

Lowe, P. A. (2018). An investigation into the psychometric properties of the Test Anxiety Measure for College Students. *Journal of Psychoeducational Assessment*, *36*(4), 322–336. http://doi.org/10.1177/0734282916678536

Lowe, P. A., Lee, S. W., Witteborg, K. M., Prichard, K. W., Luhr, M. E., Cullinan, C. M., … Janik, M. (2008). The Test Anxiety Inventory for Children and Adolescents (TAICA). *Journal of Psychoeducational Assessment*, *26*(3), 215–230. http://doi.org/10.1177/0734282907303760

Mandler, G., & Sarason, S. (1952). A study of anxiety and learning. *Journal of*

Abnormal and Social Psychology, *47*(2), 166–173. http://doi.org/10.1037/h0062855

Mcauley, T., Chen, S., Goos, L., Schachar, R., & Crosbie, J. (2010). Is the behavior rating inventory of executive function more strongly associated with measures of impairment or executive function? *Journal of the International Neuropsychological Society*, *16*(3), 495–505. http://doi.org/10.1017/S1355617710000093

McCraty, R., & Shaffer, F. (2015). Heart rate Variability: new perspectives on physiological Mechanisms, assessment of self-regulatory Capacity, and Health risk. *Global Advances in Health and Medicine*, *4*(1), 45–61. http://doi.org/10.7453/gahmj.2014.073

McDonald, A. S. (2001). The Prevalence and Effects of Test Anxiety in School Children, *21*(1).

Mowbray, T. (2012). Working memory, test anxiety and effective interventions: A review. *Australian Educational and Developmental Psychologist*. http://doi.org/10.1017/edp.2012.16

Müller, U., Mottweiler, E., & Bublak, P. (2005). Noradrenergic blockade and numeric working memory in humans. *Journal of Psychopharmacology*, *19*(1), 21–28. http://doi.org/10.1177/0269881105048888

Nelson, J. M., Lindstrom, W., & Foels, P. A. (2013). Test Anxiety Among College Students With Specific Reading Disability (Dyslexia): Nonverbal Ability and Working Memory as Predictors. *Journal of Learning Disabilities*, *48*(4), 422–432. http://doi.org/10.1177/0022219413507604

Ng, E. L., & Lee, K. (2015). Effects of trait test anxiety and state anxiety on children's working memory task performance. *Learning and Individual Differences*, *40*, 141–148. http://doi.org/10.1016/j.lindif.2015.04.007

O'Donnell, P. S. (2017). Executive Functioning Profiles and Test Anxiety in College Students. *Journal of Psychoeducational Assessment*, *35*(5), 447–459. http://doi.org/10.1177/0734282916641554

Owens, M., Stevenson, J., Hadwin, J. A., & Norgate, R. (2014). When does anxiety help or hinder cognitive test performance? The role of working memory capacity. *British Journal of Psychology*, *105*(1), 92–101. http://doi.org/10.1111/bjop.12009

Putwain, D. (2008). Deconstructing test anxiety. *Emotional and Behavioural Difficulties*, *13*(2), 141–155. http://doi.org/10.1080/13632750802027713

Putwain, D. (2018). An examination of the self-referent executive processing model of test anxiety: Control, emotional regulation, self-handicapping, and examination performance. *European Journal of Psychology of Education*, pp. 1–18. http://doi.org/10.1007/s10212-018-0383-z

Putwain, D., & Daly, A. L. (2014). Test anxiety prevalence and gender differences in a sample of English secondary school students. *Educational Studies*, *40*(5), 554–570. http://doi.org/10.1080/03055698.2014.953914

Qin, S., Hermans, E. J., van Marle, H. J. F., Luo, J., & Fernández, G. (2009). Acute Psychological Stress Reduces Working Memory-Related Activity in the Dorsolateral Prefrontal Cortex. *Biological Psychiatry*, *66*(1), 25–32. http://doi.org/10.1016/j.biopsych.2009.03.006

Rabbitt, P., Maylor, E., McInnes, L., Bent, N., & Moore, B. (1995). What goods can self-assessment questionnaires deliver for cognitive gerontology? *Applied Cognitive Psychology*, *9*(7), S127–S152. http://doi.org/10.1002/acp.2350090709

Robinson, A. M. (2018). Let's talk about stress: History of stress research. *Review of General Psychology*, *22*(3), 334–342. http://doi.org/10.1037/gpr0000137

Sarason, I. (1984). Stress, anxiety, and cognitive interference: Reactions to tests. *Journal of Personality and Social Psychology*, *46*(4), 929–938. http://doi.org/10.1037/0022-3514.46.4.929

Sarason, S., & Mandler, G. (1952). Some correlates of test anxiety. *Journal of Abnormal and Social Psychology*, *47*(4), 810–817. http://doi.org/10.1037/h0060009

Segool, N. K., Carlson, J. S., Goforth, A. N., von der Embse, N., & Barterian, J. A. (2013). Heightened test anxiety among young children: Elementary school students' anxious responses to high-stakes testing. *Psychology in the Schools*, *50*(5), 489–499. http://doi.org/10.1002/pits.21689

Segool, N. K., von der Embse, N., Mata, A. D., & Gallant, J. (2014). Cognitive Behavioral Model of Test Anxiety in a High-Stakes Context: An Exploratory Study. *School Mental Health*, *6*(1), 50–61. http://doi.org/10.1007/s12310-013-9111-7

Seipp, B. (2007). Anxiety and academic performance: A meta-analysis of findings. *Anxiety Research*, *4*(1), 27–41. http://doi.org/10.1080/08917779108248762

Sommer, M., & Arendasy, M. E. (2014). Comparing different explanations of the effect of test anxiety on respondents' test scores. *Intelligence*, *42*(1), 115–127. http://doi.org/10.1016/j.intell.2013.11.003

Spielberger, C. D. (1980). *Test Anxiety Inventory*. *Corsini Encyclopedia of Psychology*. http://doi.org/10.1002/9780470479216.corpsy0985

Steward, K. A., Tan, A., Delgaty, L., Gonzales, M. M., & Bunner, M. (2017). Self-Awareness of Executive Functioning Deficits in Adolescents With ADHD. *Journal of Attention Disorders*, *21*(4), 316–322. http://doi.org/10.1177/1087054714530782

Stone, J. M., & Towse, J. N. (2015). A Working Memory Test Battery: Java-Based Collection of Seven Working Memory Tasks. *Journal of Open Research Software*, *3*. http://doi.org/10.5334/jors.br

Strawn, J. R., Hamm, L., Fitzgerald, D. A., Fitzgerald, K. D., Monk, C. S., & Phan, K. L. (2015). Neurostructural abnormalities in pediatric anxiety disorders. *Journal of Anxiety Disorders*, *32*, 81–88. http://doi.org/10.1016/j.janxdis.2015.03.004

Suhr, J., & Wei, C. (2013). Symptoms as an excuse: Attention Deficit/Hyperactivity Disorder symptom reporting as an excuse for cognitive test performance in the context of evaluative threat. *Journal of Social and Clinical Psychology*, *32*(7), 753–769. http://doi.org/DOI:10.1521/jscp.2013.32.7.753

Szafranski, D. D., Barrera, T. L., & Norton, P. J. (2012). Test anxiety inventory: 30 years later. *Anxiety, Stress & Coping*, *25*(6), 667–677.

http://doi.org/10.1080/10615806.2012.663490

Taylor, R. G. (1964). Personality traits and discrepant achievement: A review. *Journal of Counseling Psychology*, *11*(1), 76–82. http://doi.org/10.1037/h0040859

Thomas, C. L., Cassady, J. C., & Finch, W. H. (2018). Identifying Severity Standards on the Cognitive Test Anxiety Scale: Cut Score Determination Using Latent Class and Cluster Analysis. *Journal of Psychoeducational Assessment*, *36*(5), 492–508. http://doi.org/10.1177/0734282916686004

Tobias, S. (1979). Anxiety research in educational psychology. *Journal of Educational Psychology*, *71*(5), 573–582. http://doi.org/10.1037/0022-0663.71.5.573

Tobias, S. (1985). Test Anxiety: Interference, Defective Skills, and Cognitive Capacity. *Educational Psychologist*, *20*(3), 135–142. http://doi.org/10.1207/s15326985ep2003_3

von Bastian, C. C., Locher, A., & Ruflin, M. (2013). Tatool: A Java-based open-source programming framework for psychological studies. *Behavior Research Methods*, *45*(1), 108–115. http://doi.org/10.3758/s13428-012-0224-y

von der Embse, N., Barterian, J., & Segool, N. (2013). Test Anxiety Interventions for Children and Adolescents: A Systematic Review of Treatment Studies from 2000-2010. *Psychology in the Schools*, *50*(1), 57–71. http://doi.org/10.1002/pits.21660

von der Embse, N., Jester, D., Roy, D., & Post, J. (2017). Test anxiety effects, predictors, and correlates: A 30-year meta-analytic review. *Journal of Affective Disorders*. http://doi.org/10.1016/j.jad.2017.11.048

Walitt, B., Čeko, M., Khatiwada, M., Gracely, J. L., Rayhan, R., Vanmeter, J. W., & Gracely, R. H. (2016). Characterizing "fibrofog": Subjective appraisal, objective performance, and task-related brain activity during a working memory task. *NeuroImage: Clinical*, *11*, 173–180. http://doi.org/10.1016/j.nicl.2016.01.021

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale.* (4th ed.). San Antonio, TX: Pearson.

Welch, L., & Rennie, T. A. C. (1951). The influence of psychopathological emotions on psychological test performance. *Relation of Psychological Tests to Psychiatry.* New York City: Grune & Stratton. http://doi.org/10.1037/11276-015

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, 459–482. http://doi.org/10.1002/cne.920180503

APPENDICES

A. University of Windsor Psychology Participant Pool Advertisement

Psychology Participant Pool Ad
Study Name: Perception and Performance of Working Memory: Insights into Test Anxiety

Brief Abstract: The purpose of this study is to determine how different methods of measuring a cognitive skill, working memory, predict test anxiety.

Eligibility Criteria:

- You are fluent in English
- You are taking the survey on a device with audio capabilities

Duration: 60 minutes

Points: 1

Preparation: Please complete the survey in a quiet, private place, where you can listen to audio clips and won't be interrupted.

B. Demographic Questionnaire

Age: _________________

Year of study: _________________

Grade point average: _________________

1. Is English your first language? If no, are you fluent in English?
2. Have you ever been diagnosed with a hearing or visual impairment that would affect your ability to hear or see the tasks required for this testing session?
3. Have you ever been diagnosed with ADHD or a learning disorder?
4. Have you ever been diagnosed with a neurological disorder (e.g. stroke, multiple sclerosis)?
5. Have you ever had a traumatic brain injury or concussion?
6. Are you currently experiencing severe anxiety, depression, manic symptoms?

VITA AUCTORIS

NAME:	Rebecca Grossman
PLACE OF BIRTH:	Detroit, MI
YEAR OF BIRTH:	1991
EDUCATION:	Akiva Hebrew Day School, Southfield, MI, 2009
	University of Michigan, B.S., Ann Arbor, MI, 2014
	Madonna University, M.S., Livonia, MI, 2017
	University of Windsor, M.A., Windsor, ON, 2020