

Elucidating the Relationship Between Anxiety and Working Memory: An
Examination of Domain-General and Domain-Specific Interference

by

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ABSTRACT

While research consistently links high levels of anxiety to poor working memory performance, the underlying mechanisms of this relationship have been widely debated. Under Processing Efficiency Theory/Attention Control Theory (Eysenck & Calvo, 1992), the relationship is said to reflect domain-general interference, where anxiety disrupts broad central executive functions within working memory (e.g., filtering irrelevant stimuli). Conversely, proponents of the Two Component Model (Vytal et al., 2012) argue for domain-specific interference, where specific aspects of anxiety (i.e., worry and arousal) interfere with specific working memory domains (i.e., phonological and visuospatial, respectively). The current research compared these two models and considered Moran's (2016) claim that the models are complementary. Undergraduate students (N=60) completed a *simple* change detection task to examine baseline working memory capacity and a *complex* change detection task to examine filtering efficiency. These tasks were completed with both phonological (words) stimuli and visuospatial (faces) stimuli. In the complex change detection task, participants were instructed to remember target stimuli while ignoring distractor stimuli, the latter of which were either neutral or threatening (i.e., negatively valenced) in nature. Participants also self-reported their levels of trait arousal and trait worry. Linear mixed effects model comparisons were conducted across phonological and visuospatial versions of the simple and the complex change detection task. Results from the complex change detection task with phonological stimuli highlight a domain-general relationship between worry and working memory. Results from the complex change detection task with visuospatial stimuli highlight domain-specific interference of arousal with visuospatial working

memory in terms of accuracy, but a domain-general relationship was observed between arousal and processing efficiency (i.e., response time). Examination of performance on the baseline change detection task revealed no support for explanatory models.

Regression analyses highlighted unique predictive effects of baseline working memory storage capacity on filtering efficiency as a function of stimulus type (i.e., phonological versus visuospatial) and nature of distractors (i.e., threat or neutral). Implications of results in terms of elucidating the nature of the relationship between trait anxiety (i.e., worry and arousal) and working memory are considered, along with discussion of limitations and directions for future research in this area.

Table of Contents

ABSTRACT	ii
Table of Contents	iv
List of Tables.....	vii
List of Figures	viii
Elucidating the Relationship between Anxiety and Working Memory: An Examination of Domain-General and Domain-Specific Interference	1
Working Memory.....	3
Explanatory Model of Working Memory	4
Empirical Methods to Investigate the Multiple Component Model.....	9
Anxiety	10
Components of Anxiety	12
Nature of the Relationship between Anxiety and Working Memory	14
Anxiety and Working Memory in the Context of Filtering Efficiency.....	16
Models of the Anxiety and Working Memory Relationship.....	26
Domain-General Interference: Processing Efficiency Theory/Attentional Control Theory	26
Limitations and Further Considerations of PET/ACT	34
Domain-Specific Interference: The Two Component Model	36
Limitations and Further Considerations of the Two Component Model	39
Resolving the Debate? Moran’s (2016) Proposed Theory	42
Current Study: Research Questions and Contributions.....	44
Method	51

Participants	51
Measures and Tasks	52
Apparatus	68
Procedure.....	69
Data Analysis	70
Results	76
Research Question 1: Filtering efficiency	76
Research Question 2: Baseline Working Memory Storage Capacity	82
Research Question 3: Relationship between WM storage capacity and Filtering Cost	88
Research Question 4: Processing Efficiency (Response Time)	91
Discussion	93
Research Question 1	94
Research Question 2.....	105
Research Question 3.....	107
Research Question 4.....	110
General Discussion and Theoretical Implications.....	112
Strengths, Limitations, and Future Directions	115
Conclusions	121
References	123
Appendix A	139
Appendix B	140

Appendix C: Pilot study	141
Participants	143
Measures	143
Procedure.....	144
Results	145
Strategies	145
Working Memory	146
Discussion	147
Cirriculum Vitae	

List of Tables

Table 1. Overview of key models of the anxiety and working memory relationship.	27
Table 2. Summary of research questions	47
Table 3. Descriptive statistics of psycholinguistic data for the word stimuli.	29
Table 4. Average accuracy by Distractor Type for phonological and visuospatial versions of the complex (filtering) change detection task	77
Table 5. Average filtering cost by Distractor Type for phonological and visuospatial versions of the complex (filtering) change detection task.	80
Table 6. Average accuracy by Set Size for phonological and visuospatial versions of the baseline change detection task	83
Table 7. Average working memory capacity (Pashler's K) by Set Size for phonological and visuospatial versions of the baseline change detection task	86
Table A1. Mean accuracy rate by Set Size and Stimulus Duration.	148

List of Figures

Figure 1. Visual depiction of the filtering efficiency task utilized by Stout and colleagues (2013; 2015).	22
Figure 2. Potential model of the relationship between anxiety and working memory as proposed by and presented in the Moran (2016) review.	43
Figure 3. Visual depiction of trials for the phonological version of the change detection task.	65
Figure A1. Average accuracy by Set Size (2/3/4/5/6) and Stimulus Duration (250 ms/500 ms/1000 ms).	149

Elucidating the Relationship between Anxiety and Working Memory: An Examination of Domain-General and Domain-Specific Interference

High anxiety is a widespread concern that is often associated with functional impairments in multiple areas of life (e.g., personal, employment, academic, social; American Psychiatric Association, 2013). Anxiety has shown reliable associations with impaired performance on cognitive tasks, including problem solving, reading comprehension, and visual search tasks (see Moran, 2016 for review). Much research has attributed the association between anxiety and cognition to anxiety's dynamic and bi-directional relationship with working memory, or the ability to temporarily maintain, manipulate, and recall information presented in the environment (Baddeley, 2012; Cowan, 2005). Anxiety has been shown to interfere with the capacity and successful functioning of working memory, such that it competes with working memory for similar neural resources and thus reduces the availability of such resources for the performance of cognitive tasks (e.g., Ashcraft & Kirk, 2001; Shackman et al., 2006). Additionally, individuals with high anxiety show an attentional bias to threat and exhibit deficits in performing cognitive tasks, both of which have been linked to impaired working memory functioning (e.g., Eysenck & Calvo, 1992; Ouimet et al., 2009). The present dissertation contributes to elucidating this complex relationship between anxiety and working memory.

While research consistently links high levels of anxiety to poor working memory performance, the underlying mechanisms of this relationship have been widely debated.

In a systematic review of the relationship between anxiety and working memory, Moran (2016) highlighted several inconsistencies and incongruencies within this research, namely an inconsistent approach to measuring and defining anxiety, as well as apparent contradictions and differential focus on certain aspects of anxiety and working memory among proposed models of this relationship. The current dissertation addresses such inconsistency by examining two models— the Processing Efficiency Theory/Attention Control Theory (PET/ACT; Eysenck & Calvo, 1992; Eysenck et al., 2007) and the Two Component Model (Vytal et al., 2012; 2013). Although there are many models of working memory in the literature, these two models have been influential in explaining the relationship between anxiety and working memory but are somewhat contradictory. Under the PET/ACT account, anxiety is said to interfere with working memory in a domain-general manner in that it disrupts general working memory functions such as inhibition (Eysenck & Calvo, 1992; Eysenck et al., 2007). In contrast, within the Two Component Model, the interference is said to be domain-specific such that different components of anxiety (e.g., worry and arousal) differentially disrupt working memory depending upon the type of stimuli (e.g., phonological or visuospatial) involved in the task or situation (Vytal et al., 2012; 2013). To clarify the concepts underlying the purpose of my dissertation, I first consider the constructs of working memory and anxiety and how they are defined, which itself highlights a crucial issue that such constructs have been inconsistently and indistinctly defined in previous literature (Moran, 2016). The current research was designed to examine whether the PET/ACT account or the Two Component Model better accounts for the relationship between working memory and anxiety, or whether the two are complementary. The apparent

inconsistencies between these models are directly addressed by examining both domain-general and domain-specific interference in a single sample of participants.

Working Memory

Working memory (WM) has been described as “the blackboard” of the human mind (see Miyake & Shah, 1999) in that it allows one to temporarily maintain, manipulate, and recall information. It refers to aspects of on-line cognition, such as the moment-to-moment monitoring, processing, and maintenance of information on a short-term basis (Baddeley, 1986). Working memory is brief in nature and may not include a long-term store of information (e.g., Baddeley, 1986). The workspace of working memory is limited in capacity, such that a limited amount of information can be maintained, manipulated, and recalled at any given time (Baddeley, 2002; Cowan, 2005).

Working memory has widespread and important functions. These include: understanding and mentally representing the immediate environment; sustaining attention to accomplish a goal or to complete a task; retaining information about immediate past experience; supporting the acquisition of new knowledge; and directing action when faced with potential sources of distraction or interference (e.g., Baddeley, 1986; Miller & Cohen, 2001). Effective working memory functioning can be disrupted. Specifically, each component of working memory has constraints which may arise in terms of an individual’s capacity to activate working memory, capacity to engage in rehearsal of information, capacity to handle complex material, as well as the level of support working memory receives from acquired strategies and prior knowledge (Baddeley, 1986).

In addition to these potential constraints within working memory, there are also individual differences in Working Memory Capacity (WMC). According to the attentional account of WMC (Engle, 2002), such differences are driven by an individual's ability to select relevant information, resist distraction, and maintain access to relevant information that is potentially useful but is not within one's immediate awareness. These abilities may vary across individuals and are influenced by individual and external factors (e.g., internally generated worry thoughts, distractor(s) in the immediate environment; Moran, 2016). Importantly for the current research, working memory capacity is also associated with individual differences in dispositional anxiety, such that anxiety competes for cognitive resources and interferes with working memory capacity (Moran, 2016).

Explanatory Model of Working Memory

Many researchers have attempted to account for the complex skill of working memory, and as such, many models of working memory exist in the literature (e.g., see Miyake & Shah, 1999, for review). I will focus on the *multiple component model* (Baddeley & Hitch, 1974) and will thus define working memory according to this model. I chose this model because it has received much empirical support and is arguably the most prominent and widely cited model in the area of working memory (e.g., Ashkenazi et al., 2013; Baars & Franklin, 2003) and in the literature examining the relationship between anxiety and working memory (see Moran, 2016 for review). Use of Baddeley's model within the current dissertation was primarily as a scaffolding device from which to understand or interpret results within the broader working memory and anxiety literature. Understanding domain-specific versus domain-general

interference in this relationship does not depend on tenets from Baddeley's model, and in fact, many of the experimental findings supporting these two concepts can be understood using other valuable working memory models, including the Feature Model (Nairne, 1988, 1990, 2001), and Cowan's Embedded Processes model (Cowan, 1999). Within such models, in contrast to the multiple component model (described in detail below), working memory is not considered modular—that is, verbal and visuospatial representations are not considered independent. Nevertheless, the current work focused on Baddeley's model primarily due to the significant representation of this model in the anxiety and working memory literature.

The *multiple component model* divides working memory into **domain-specific** and **domain-general** components. It posits that working memory involves **domain-specific stores**, which are responsible for storing specific types of information (e.g., verbal, visual). The *phonological loop* is the domain-specific store dealing with verbally coded information (e.g., words, numbers; Baddeley & Hitch, 1974). Examination of this component through experimental, neuropsychological, and neuroimaging studies has revealed two subcomponents. The first is the *passive phonological store*, where verbal information is held on a temporary basis. This store is responsible for verbal material that is presented auditorily, as well as for visually presented information that the individual has coded phonologically (through silent articulation). The information held within the phonological store naturally decays with time. The second subcomponent of the phonological loop is the *active rehearsal process*, which serves to refresh the decaying representations in the phonological store and allows the information to be maintained (Baddeley, 1986; 2007). To demonstrate the importance of active rehearsal

in working memory, researchers have used articulatory suppression—where participants are required to repeatedly say an unrelated word or phrase out loud (e.g., repeat the word “the” out loud) during the presentation of to-be-recalled words or letters. Baddeley (1986; Baddeley et al., 2019) suggested that articulatory suppression prevents participants from verbally rehearsing the to-be-remembered items, thus preventing their active maintenance in working memory and leading to greater decay and forgetting. Indeed, when participants engage in articulatory suppression during the study of words or letters, fewer to-be-remembered stimuli are later recalled (Baddeley et al., 2019; Murray, 1968). Rehearsal is thus a key strategy for enhancing working memory performance with respect to verbal information (Baddeley, 1986; 2007).

The second domain-specific store is the *visuospatial sketchpad*, which deals with visual and spatial information and allows us to mentally visualize images that are currently in view or have been viewed in the recent past (Baddeley & Hitch, 1974). This component has also been divided into two subcomponents: a *passive visual cache*, which handles the maintenance of visual information including color and visual form; and *the inner scribe*, which actively rehearses information from the visual cache, handles spatial and movement information, and is involved in planning and executing body movements (Baddeley, 2007). The *visual cache* has been linked to tasks that require memory for visual information, such as visual pattern recall (e.g., remembering the location of black squares within a matrix of black and white squares; Holmes et al., 2008). In contrast, the *inner scribe* has been linked to tasks requiring memory for spatial information or movement, such as block recall which requires participants to recall and repeat a spatial sequence that is tapped out on blocks (Corsi, 1972).

In addition to the domain-specific components, the working memory system includes a **domain-general attention system**, known as the *central executive*, which assumes a supervisory role over the other components of working memory and serves to control and regulate the entire working memory system (Baddeley, 1986; 2002; 2007). The *central executive* is responsible for various executive functions, and may fulfill five major functions: switching attention between tasks; planning subtasks to achieve a goal; focusing attention on relevant information and processes and inhibiting irrelevant ones (e.g., selective attention and inhibition); updating and checking the contents of working memory; and coding representations in working memory for time and place of appearance (Baddeley, 1986; 2002; 2007; Eysenck et al., 2007). Unlike the other working memory components, the *central executive* does not include a storage component (Baddeley, 1986; 2002; 2007).

The original multiple component model was later modified via the addition of a fourth component of working memory: the *episodic buffer* (Baddeley, 2000; 2002). This buffer was proposed to explain unexpected results from studies examining working memory that were unaccounted for by the earlier version of the model. This included how individuals combine phonological and visuospatial material together in working memory and how they transfer information from working memory to long term memory (Baddeley, 2000). This component is thus defined as a temporary store of information (e.g., phonological and visuospatial) that binds multiple sources of information together into meaningful “chunks” or “episodes” to be transferred to long-term memory (Baddeley, 2000). Performance of the episodic buffer has not yet been linked to

individual differences in anxiety (Eysenck et al., 2005; Moran, 2016), so it will not be considered further here.

More recently, additional considerations to the original model were outlined by Baddeley, Hitch, and Allen (2021). The authors highlight that information enters working memory through peripheral sources (e.g., through the senses, including vision, touch, hearing) and is temporarily stored within the storage components of the multiple component and modular model (e.g., phonological loop and visuospatial sketchpad) which are said to be more complex than originally proposed. Specifically, each of the storage components are said to be able to combine and compress information from incoming streams of phonological and visuospatial information into broad representations. A multidimensional representation may then be formed with influence from long-term memories using the episodic buffer which is available to conscious awareness and is thus influenced by long-term memories. As well, it is argued that selective attention processes allow some information to be prioritized within the focus of attention, a process which is also said to be carried out by the episodic buffer. The central executive is said to be responsible for guiding the direction of attention toward goal-relevant information during encoding, identifying and implementing strategies to optimize task goals, maintaining items within the focus of attention such as through attentional refreshing, and retrieving items into the focus of attention at the time of recall (Baddeley et al., 2021). This updated view was said to better account for cross-modality interference as auditory and visual input may compete for storage within the focus of attention/episodic buffer as well as limited resources from the central executive (Baddeley et al., 2021). Moreover, it is argued that visuospatial storage may require

greater resources from the central executive for maintenance compared to phonological which is benefited by active verbal rehearsal. Baddeley and colleagues (2021) indicated that the visuospatial sketchpad may be subject to rapid forgetting which can involve overwriting or interference. They suggest that attentional control within working memory thus involves both internal components (e.g., to refresh items within the stores) and external components (e.g., to select and/or prioritize items to remember and to ignore distractors) and argue that the external component may be a source of overwriting or interference within working memory.

Empirical Methods to Investigate the Multiple Component Model

Because of the presumed complexity of working memory, it is common to utilize *dual-task paradigms* in the study of working memory. In dual-task paradigms, participants are asked to concurrently perform combinations of tasks that are thought to rely on unique components of working memory (e.g., articulatory suppression tasks involve the phonological loop; spatial tapping or block recall tasks involve the visuospatial sketchpad). Dual-task paradigms are utilized as they are thought to better reflect the multiple demands placed on the working memory system. In addition, they allow examination of the underlying cognitive mechanisms of various tasks and experiences and the competition or interference that may result between components of working memory. It is assumed that if two tasks rely on the same underlying resources (i.e., the same working memory components), then performance in one or both tasks in a dual-task paradigm will be impaired (Moran, 2016). Baddeley's multiple component model assumes that *individual* components of working memory can be more (or less) involved in one aspect of an activity or task and may (or may not) continue to function

despite distraction or interference involving another component (Baddeley, 2002; Moran, 2016). When interference does occur, it suggests the same components of working memory are taxed by both tasks or activities, thus providing insight into the underlying mechanisms of such tasks or activities (Moran, 2016). This technique is therefore a useful behavioural method to infer the cognitive processes inherent in a particular task, activity, or experience.

Anxiety

Anxiety is a widespread experience and, when heightened, is associated with functional impairments in multiple areas of life (e.g., personal, employment, academic, social; American Psychiatric Association, 2013). When severe and persistent enough to warrant a psychiatric diagnosis, anxiety disorders are debilitating and associated with substantial morbidity and mortality (e.g., American Psychiatric Association, 2013; Kessler et al., 2012). Anxiety can be experienced dispositionally (Spielberger et al., 1983) and/or situationally (Spielberger et al., 1970; Spielberger & Sydeman, 1994). *Trait* (or dispositional) anxiety refers to an enduring aspect of an individual's personality that predisposes them to generally perceive situations as threatening (Spielberger et al., 1983). In contrast, *state* (or situational) anxiety, refers to the feelings of uneasiness that result when one perceives a particular situation to be threatening (Spielberger et al., 1970; Spielberger & Sydeman, 1994). State anxiety is sensitive to a wide range of situational stresses, while trait anxiety is a more permanent personality disposition and tends to remain stable over time and across situations (Spielberger et al., 1970).

Trait and state anxiety are argued to be distinct experiences. For example, an individual with low trait anxiety may experience significant state anxiety under certain

circumstances, such as when exposed to the threat of shock in a laboratory setting (Shackman et al., 2006). The experience of state anxiety also varies within individuals, such that those with high trait anxiety may not consistently show elevated state anxiety when exposed to potentially threatening situations (Meissel & Salthouse, 2016; Waldstein et al., 1997). However, trait and state anxiety often overlap and interact with one another and have been shown to be highly correlated (Spielberger, 2013), so that these anxiety types are difficult to tease apart.

Relative to state anxiety, trait anxiety has been neglected in the literature examining the relationship between working memory and anxiety (see Moran, 2016). Much of the research examines the relationship by experimentally inducing symptoms of anxiety among participants (e.g., Shackman et al., 2006; Vytal et al., 2012). For example, the threat-of-shock paradigm involves telling participants that they are at risk of experiencing unpleasant electrical shocks on “threat” trials with intent to elicit anticipatory anxiety on those trials (Grillon et al., 2004). This anticipatory anxiety is situational in nature and thus is a measure of state anxiety. Unfortunately, such previous studies do not include a complementary measure of trait anxiety, thus limiting our understanding of how participants’ predisposed level of trait anxiety may be related to working memory performance in this context. When trait anxiety has been considered in this research, unique relationships have been shown with working memory performance (e.g., Vytal et al., 2016), underscoring the need to explore this type of anxiety further. Due to the difficulty of teasing trait and state anxiety apart, it is important to make attempts to focus on one anxiety type in the current work. Due to the relative neglect of trait anxiety in this area (see Moran, 2016) and the unique relationships that have been

shown when trait anxiety has been considered (e.g., Vytal et al., 2016), the current study focused on trait anxiety. In the remaining review of past literature, I do not distinguish between state and trait anxiety unless relevant.

In empirical studies, anxiety is often treated as a categorical variable by grouping participants into high and low anxiety groups on the basis of their scores on self-report measures (e.g., Qi et al., 2014). This is sometimes accomplished by selecting participants whose scores on an anxiety measure fall in the extremes of the distribution. For example, Qi and colleagues (2014) categorized those who scored in the upper 27th percentile of the distribution of scores on the State Trait Anxiety Inventory as a high anxiety group, and those who scored in the lower 27th percentile as a low anxiety group. Creating categorical groups can also be accomplished through a median split approach. These approaches (i.e., deriving categories from continuous variables) have received criticism as they involve artificially or arbitrarily assigning a cut-off score, may reduce statistical power, and may interfere with the accuracy of estimated relations (e.g., Cohen, 1983; DeCoster et al., 2011). Thus, continuous variables should be analyzed in their original form rather than creating artificial categories (e.g., Humphreys, 1978). While my study has been informed by research that has utilized categorical classifications of anxiety (e.g., high versus low anxiety), my dissertation examines all anxiety variables as continuous variables.

Components of Anxiety

To further add to the complexity in defining anxiety, the literature has identified anxiety as a heterogeneous construct consisting of multiple underlying components which have shown unique relationships with various cognitive functions, including

working memory (Andrews & Borkovec, 1988; Heller & Nitschke, 1998). Although models of anxiety exist that propose three or four components (Clark & Watson, 1991; Koksal & Power, 1990, respectively), the most common and agreed upon categorization of anxiety in the working memory and anxiety literature involves just two components (e.g., see Moran, 2016 for review). Those two components are: *anxious arousal*, which refers to physiological hyperarousal and somatic tension and is often associated with physical symptoms of anxiety (e.g., increased heart rate, hypervigilance, sweaty palms, dizziness); and *worry* (also termed *anxious apprehension*), which refers to verbal rumination and preoccupation with potential negative outcomes of future events (Watson et al., 1995). Anxious arousal and worry have been shown to be independent and distinct experiences and are associated with unique patterns of brain activity (e.g., Barlow, 1991; Nitschke et al., 2001). These two types of anxiety can co-occur within one individual, such as in the case of someone who experiences panic attacks (e.g., heightened anxious arousal symptoms) and has persistent worry about the consequences of such symptoms and of future attacks (Nitschke et al., 2001). However, the correlation between anxious arousal and worry has been shown to be weak, supporting their distinction (e.g., $r = .20$; Nitschke et al., 2001). The distinction between these two anxiety dimensions is useful for differentiating specific anxiety disorders. For instance, worry is a key variable used to differentiate Generalized Anxiety Disorder from other anxiety disorders, while anxious arousal often differentiates Panic Disorder (American Psychiatric Association, 2013; Nitschke et al., 2001).

The distinction between arousal and worry and their relation to state versus trait anxiety is unclear. Anxious arousal is often observed during stressful circumstances and

situations, thus appearing to align best with state anxiety (Watson et al., 1995). Trait anxiety often shows strong positive correlations with worry, such that individuals prone to worry are likely to experience anxiety about multiple future situations and events and perceive such situations as threatening (Watson et al., 1995). However, individuals with high trait anxiety also experience anxious arousal (e.g., physical symptoms of anxiety) and state anxiety may or may not also involve active worry (e.g., about potential negative outcomes of a current situation; Beilock et al., 2007; Moran, 2016). As such, both arousal and worry subcomponents of anxiety should be considered when assessing state and trait anxiety (Moran, 2016).

Nature of the Relationship between Anxiety and Working Memory

Various researchers have tried to understand the nature of the relationship between anxiety and working memory. One suggestion is that some information is more likely to be attended to (and thus enter working memory) due to cognitive biases that occur in those with anxiety. Individuals with high anxiety show a cognitive bias to negative or potentially threatening information (e.g., Bishop, 2007; Mathews & MacLeod, 1994). For instance, individuals with high trait anxiety have been shown to attend to negative stimuli faster and to recall such stimuli more easily in comparison to neutral stimuli (e.g., Sass et al., 2010). Such facilitated attention and memory recall for negative stimuli is unique to high trait anxiety and is not typically observed in individuals with low trait anxiety (e.g., Yiend, 2010). These cognitive biases have been linked to impaired working memory functioning among those with heightened anxiety (Eysenck & Calvo, 1992; Ouimet et al., 2009).

There exists debate in the literature regarding the causal direction of the relationship between anxiety and cognitive deficits, including working memory deficits. Some argue that cognitive deficits, such as poorer working memory and executive functioning (e.g., inhibiting, shifting, updating), are causal factors in the development of anxiety (see Moran, 2016 for review). Several studies have documented impaired working memory capacity among those with anxiety (e.g., Ashkraft & Kirk, 2001; Shackman et al., 2006). Processes which are thought to rely on working memory, including negative interpretation biases and attention biases to threat, have also been linked to the development of anxiety (e.g., Mathews & MacLeod, 2005; Moran, 2016). MacLeod and colleagues (2002) showed support for this view by having participants complete a dot probe task where they were asked to identify the location of a dot presented on the screen (e.g., on the left or right half of the screen). Prior to presentation of the target dot, participants were presented with two words, one threatening and one neutral in nature, with one of the two words being presented in the same location as the subsequently presented target. Participants were assigned to one of two groups: the induced attention bias to threat group, where the dot probe was always presented at the same location as the threatening word, or the neutral group, where the dot was always presented at the same location as the neutral word. Later, when participants were placed in a stressful situation (i.e., when asked to solve unsolvable anagrams while being video-taped), those who had been biased to attend to threat self-reported greater anxiety than participants who were cued with neutral words (MacLeod et al., 2002). Such findings suggest that state changes in anxiety may result from cognitive biases to threat and differences in working memory functioning.

Other researchers argue for the opposite direction of causal influence in the anxiety and working memory relationship—that anxiety and its underlying components (e.g., arousal and/or worry) disrupt the various functions and components of working memory (e.g., Eysenck & Calvo, 1992; Shackman et al., 2006; Vytal et al., 2012; 2013). Sarason (1988) found that participants’ anxiety levels were significantly correlated with increased cognitive interference (i.e., increased intrusive thoughts) and decreased performance on a digit span task. It was assumed that worry thoughts interfere with and reduce the attention that could be allocated toward task performance and thus disrupt working memory performance (Sarason, 1988).

While various theories of the anxiety and working memory relationship have received empirical support, it is difficult to confidently conclude the causal direction of this relationship because much of the extant research has used correlational design. It can be concluded, however, that anxiety has a reliable and persistent relationship with working memory, and that heightened anxiety should be associated with impaired performance on working memory tasks (Moran, 2016). Although many interesting theories attempt to delineate the causality of this relationship, addressing causality is not central to the purpose of my dissertation, and as such, these theories are outside of the scope of the current literature review.

Anxiety and Working Memory in the Context of Filtering Efficiency

Individuals with high anxiety may show better ability to “tune in” attention to relevant information. For example, Berggren and Eimer (2021) found that induced anxiety was linked to faster search times in a visual search task which required them to search for one or two colours, as well as reduced costs associated with switching

between target colours. Conversely, individuals with high trait anxiety show a slowed response time when presented with distracting information while performing cognitive tasks. On search tasks where participants are asked to find, for example, all red circles in an array of red circles and diamonds, those with high trait anxiety are slower to respond when distractor shapes are present (Moran & Moser, 2015; Moser et al., 2012). This suggests that the “tuning out” of irrelevant or distracting information is the key skill that is disrupted in heightened anxiety.

Additional work has considered such distraction effects within the context of working memory storage (Moran, 2016; Vogel et al., 2005). *Working memory storage capacity*¹ refers to the amount of information that individuals can hold in working memory and is a focus of the current dissertation. From this point on, my dissertation focuses on working memory storage capacity, as well as the efficiency with which participants encode relevant information (and not irrelevant information) into working memory.

Working memory storage capacity is tested empirically using *the change detection task* (Luck & Vogel, 1997). In this task, participants are briefly presented with a study array of stimuli. Following a blank delay interval, a test array of stimuli is presented, which is either identical to the study display or includes one item that has changed. Participants are asked to determine whether the test array is the same as the study array or whether they differ. Participants’ working memory storage capacity (i.e., how much

¹ Note that *working memory storage capacity* as examined in this research is distinct from Engle’s (2002) account of working memory capacity (WMC), which equates working memory with executive attention and focuses on individual differences in the use of working memory and how it impacts the performance of cognitive tasks.

information is stored in working memory) on this task is often estimated via Pashler's K , calculated using a formula that considers the participants' hits (i.e., when they accurately detect a change on the change detection task) as well as false alarms (i.e., when they indicate a change on the task where no change has occurred).

Filtering efficiency was examined systematically for the first time by Vogel and colleagues (2005). Participants completed a filtering version of the change detection task. In this task, left- or right-pointing arrows are presented prior to the study array, indicating whether the participant should remember items on the left or right side of a computer screen, respectively (Vogel et al., 2005). Any other items in the study array are to-be-ignored. In this context, participants are thus required to remember target stimuli, while also ignoring or *filtering* interference from distracting stimuli that are presented but are not cued in the study array. Participants in Vogel and colleagues' (2005) study were classified as having "low working memory capacity" or "high working memory capacity" based on a median split of working memory storage capacity (K) scores. These classifications indexed their ability to hold items in working memory to complete the task. Results of this study showed that individuals with high storage capacity were able to filter out irrelevant distractors during the change detection task (i.e., showed greater filtering efficiency) whereas those with low storage capacity were found to store irrelevant items (i.e., un-cued distractor stimuli) along with the relevant items during the task (i.e., showed more impaired filtering efficiency). Therefore, filtering irrelevant material improved working memory performance in individuals with high capacity but failure of this process in individuals with low capacity disrupted performance (Vogel et al., 2005), highlighting the importance of filtering efficiency as

an indicator of working memory functioning. More recent work has supported this impaired filtering of distractors among those with lower visual working memory storage capacity, and suggested limitations may be greater when distractors are emotional faces (e.g., Ye et al., 2018).

Although their work did not consider anxiety, Vogel et al.'s (2005) results led Stout and Rokke (2010) to hypothesize that anxiety may be associated with impaired filtering efficiency because it impairs the ability to inhibit irrelevant or distracting information from gaining access to working memory. Stout and Rokke (2010) thus expanded earlier work by considering working memory storage capacity among individuals with heightened levels of psychological distress (as indicated through responses on the Center for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977). Using a change detection task, Stout and Rokke (2010) observed an interaction between filtering efficiency and working memory storage capacity (identified via Pashler's K), such that only individuals with low storage capacity *and* reduced ability to ignore task-irrelevant information showed impaired performance on the change detection task. Stout and Rokke also found that self-report measures of state anxiety, rumination, and depression predicted poorer filtering efficiency in the change detection task, as indicated by reduced accuracy on the task, but only for individuals with low working memory storage capacity. For high-storage capacity individuals, on the other hand, state anxiety, rumination, and depression were unrelated to filtering efficiency (Stout & Rokke, 2010).

Later work by Moriya and Sugiura (2012) extended this initial study by showing that trait anxiety and social anxiety also predicted poorer filtering efficiency on a change detection task. This study was limited as it did not examine interactions with working

memory storage capacity. Qi and colleagues (2014), however, considered trait anxiety as a categorical variable (i.e., high anxiety versus low anxiety) along with working memory capacity in this context and found an interaction effect. While poorer filtering efficiency was found among those with high trait anxiety, there was an interaction between working memory storage capacity and anxiety for low trait anxious individuals (Qi et al., 2014). Specifically, working memory storage capacity predicted filtering efficiency only for those with low trait anxiety, suggesting trait anxiety takes precedence over working memory capacity in affecting filtering efficiency (Qi et al., 2014). Together, results from previous work (e.g., Moriya & Sugiura, 2012; Qi et al., 2014; Stout & Rokke, 2010) suggest that low storage capacity and anxiety (state and trait anxiety) are each associated with reduced filtering efficiency, and while storage capacity may be a more important predictor of filtering efficiency in cases in which anxiety is low, anxiety may take precedence as a predictor of filtering efficiency when heightened (Qi et al., 2014; Stout & Rokke, 2010).

In a follow-up study, Stout and colleagues (2013) further examined filtering efficiency in relation to anxiety but considered the role of threat in this context. It was noted that anxiety-related behaviours often occur among individuals with high trait anxiety even when there is no threat in the immediate environment, which led to the postulation that such individuals may generally be less efficient at gating the access of threat into working memory (Stout et al., 2013). Thus, they utilized a filtering change detection task (example presented in Figure 1), where stimuli were neutral and fearful faces, to examine the effect of threat-related distractors (i.e., fearful faces) on working memory storage among those with varying levels of trait anxiety (Stout et al., 2013).

Participants were presented with an array of two or four faces (i.e., a face on each side of the screen or one face in each of 4 quadrants) and were cued to one hemifield (i.e., the left or right side of the screen). Within the cued hemifield, faces were indicated as targets or distractors by a (red or yellow) colored box surrounding the image.

Participants were instructed to remember the target face within the cued hemifield.

Then, participants were presented with a test array of faces and were asked to determine whether the target face had changed or remained the same. Thus, participants were required to remember the target item while ignoring distracting threatening or neutral images (including items in the un-cued hemifield and distractor items within the cued hemifield; Stout et al., 2013).

Stout and colleagues (2013) utilized a well-validated neurophysiological measure of working memory storage known as contralateral delay activity (CDA; Ikkai et al., 2010). CDA is measured using event-related potentials and electroencephalography, which involves the measurement of changes in the electrical activity occurring across the scalp in response to specific events. The CDA is a negative-going and sustained slow wave, and its amplitude is highly sensitive to the number of items maintained in working memory. Results from this study revealed that all participants, regardless of

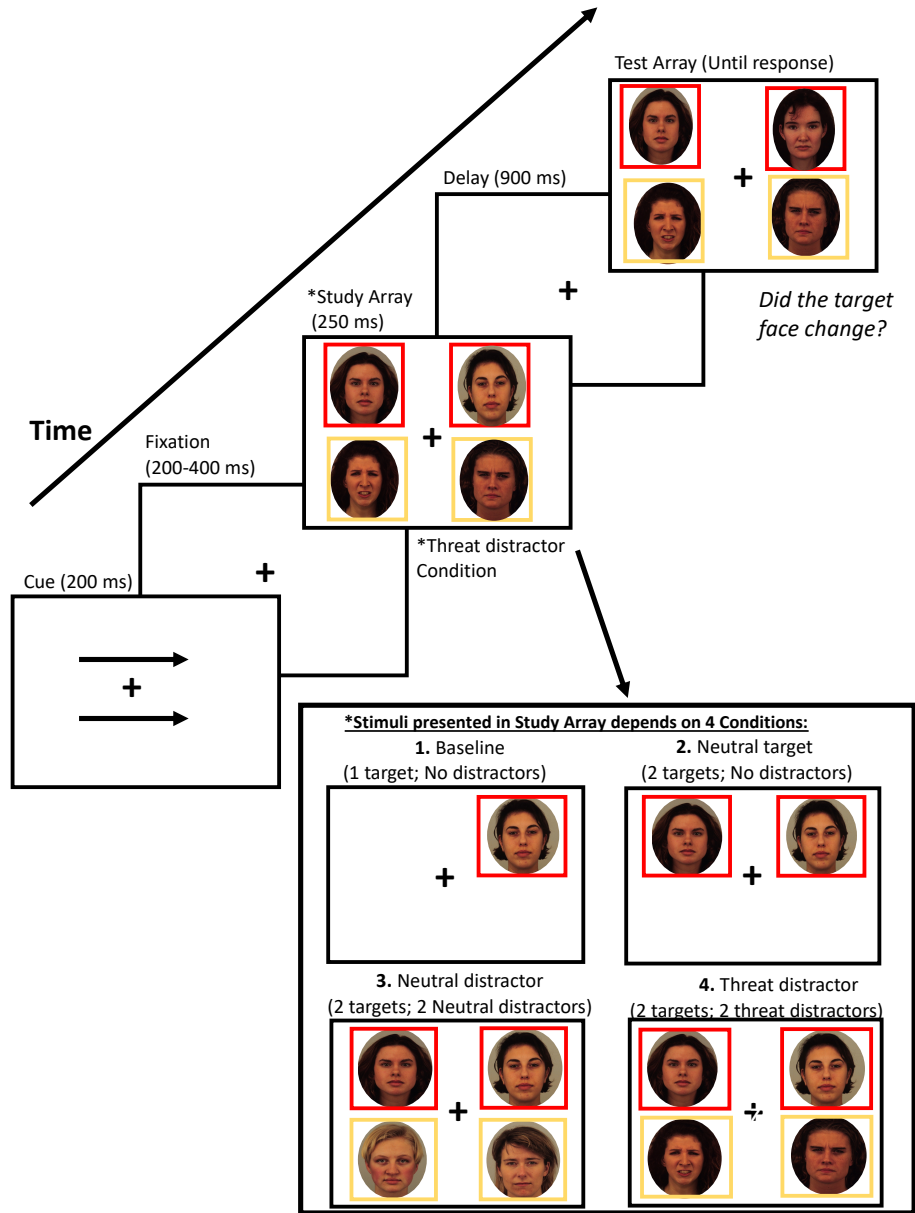


Figure 1. Visual depiction of the filtering efficiency task utilized by Stout and colleagues (2013; 2015).²

² Facial stimuli for this sample display were selected from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist et al., 1998) and include the following stimulus codes: AF29NES, AF17NES, AF28NES, AF31NES, AF08ANS, AF13ANS

anxiety level, had greater difficulty filtering or preventing distraction from threat-related distractors (i.e., un-cued fearful faces), such that they showed reduced *filtering efficiency* or an increased CDA amplitude when threat-related distractors were present in comparison to when no distractors were present. However, anxiety was negatively correlated with *filtering efficiency*, such that as anxiety increased, filtering efficiency decreased (Stout et al., 2013). This led to the conclusion that as trait anxiety levels increase, more working memory storage is allocated to threat (even when the threat is irrelevant to the task at hand), which interferes with storage of task-relevant targets (Stout et al., 2013).

Stout and colleagues (2015) conducted an additional examination of the influence of threat-related distractors on *filtering efficiency* using a behavioural estimate of filtering efficiency (i.e., Pashler's K) rather than the CDA as in their previous study. Specifically, in this study, filtering efficiency was calculated as the difference in working memory capacity (K) between trials without threatening distractors and those with (Stout et al., 2015). They measured trait anxiety using the State Trait Anxiety Inventory and considered how trait levels of worry (measured using the Penn State Worry Questionnaire; Meyer et al., 1990) may affect filtering efficiency. Of interest was whether worry and trait anxiety would be associated with difficulty gating threat and/or neutral distracting information from working memory (Stout et al., 2015). Participants completed the same filtering change detection task utilized by Stout et al. (2013). Results revealed that worry was associated with inefficient filtering of threat-related (but not neutral) distractors from working memory, while trait anxiety was related to inefficient filtering of both threat and neutral distracter stimuli. Stout et al. (2015)

concluded that the worry subcomponent of trait anxiety is uniquely associated with and characterized by a failure to inhibit task-irrelevant threat from working memory.

Notably, more recent work supports the aforementioned claims that anxiety primarily disrupts working memory performance by impairing the ability to inhibit/filter distracting information rather than limiting general working memory capacity. Bergren (2020) found that anxiety did not affect performance on a change detection task when only relevant objects were shown, but memory performance was impaired when distractor objects were also presented.

The Stout and colleagues (2015) study is limited in that it considered only one of the two subcomponents of trait anxiety. While the study provides useful information about the influence of worry on inhibition and filtering efficiency, future studies would benefit from considering the role of anxious arousal in this context, to determine if it may also be associated with filtering efficiency of threat and neutral distractors. Additionally, Stout and colleagues' work (e.g., Stout et al., 2013; 2015) made no consideration of how anxiety and worry may interact with baseline working memory storage capacity to predict change detection task performance. Given the previous results supporting such interaction (e.g., Stout & Rokke, 2010; Qi et al., 2014), my dissertation included such a baseline measure.

Overall, results across these filtering efficiency studies suggest anxiety is associated with poorer inhibition of irrelevant or distracting information. In fact, a meta-analysis pooled the effect sizes from the five aforementioned studies (i.e., Moriya & Sugiura, 2012; Qi et al., 2014; Stout & Rokke, 2010, Stout et al., 2013; 2015) to further examine the association between anxiety and filtering efficiency. Results showed that anxiety

robustly predicted poorer gating of irrelevant information from working memory ($g = -.700, p < .001$; Moran, 2016). In terms of the multicomponent model of working memory, such findings speak to interference with the domain-general system (Baddeley, 1986; Moran, 2016). Anxiety appears to be related to deficits in the central executive functioning—including decreased ability to inhibit interference from distracting information, leading to diverted attention and reduced cognitive task performance (Moriya & Sugiura, 2012; Qi et al., 2014; Stout & Rokke, 2010).

Despite the support for domain-general interference of anxiety and the inhibition function of working memory, what is not clear from these studies is whether anxiety is also associated with domain-specific functions of working memory capacity (Moran, 2016). Temporary storage of the target items is required in the change detection task (Luck & Vogel, 1997), which should rely on the domain-specific storage systems of working memory (as opposed to the domain-general system). If temporary storage within the domain-specific system of working memory is impaired or interrupted, performance on the task is likely to fail, and such failure may be independent of the influence of distracting information and filtering efficiency. If the target face is not appropriately stored in working memory, it will not be accessible at the test phase to detect a change, which may result in inaccurate performance irrespective of whether there was a threatening or neutral distractor present. In fact, Ward, Lotfi, Sallman, Lee, and Larson (2020) found that anxiety (induced using threat-of-shock paradigm) reduced working memory storage capacity on a change detection task where participants were required to detect changes in the orientation of coloured rectangles, but did not impact efficiency of filtering neutral distractors. Thus, it appears important to consider

maintenance of the target to draw accurate conclusions about the nature of impaired performance. Maintenance of the target in working memory would arguably involve the temporary storage components of working memory—namely the phonological loop and visuospatial sketchpad. Moreover, the change detection task is often visuospatial in nature, with stimuli consisting of shapes (e.g., coloured rectangles or squares; Moriya & Sugiura, 2012; Qi et al., 2014) or faces (e.g., Stout et al., 2013; 2015), and thus relies on storage in the visuospatial sketchpad. To my knowledge, no study to date has considered a verbal version of this change detection task within the context of anxiety and filtering efficiency, thus neglecting understanding of potential domain-specific interference involving the phonological loop.

Models of the Anxiety and Working Memory Relationship

Much research has attempted to explain the relationship between anxiety and working memory, with differential focus on domain-specific versus domain-general interference effects (see Moran, 2016 for review). Two proposed models within this research effectively capture these opposing views: Processing Efficiency Theory/Attentional Control Theory (PET/ACT; Eysenck & Calvo, 1992; Eysenck et al., 2007) and the Two Component Model (Vytal et al. 2012; 2013). Refer to Table 1 for a summary of these models.

Domain-General Interference: Processing Efficiency Theory/Attentional Control Theory

Early in the study of anxiety and cognitive performance, researchers hypothesized that anxiety reduces on-task effort and promotes task-avoidance (Humphreys & Revelle,

Table 1. Overview of key models of the anxiety and working memory relationship.

	Trait anxiety	Worry	Arousal	Domain-general/domain-specific interference
Processing Efficiency Theory/ Attentional Control Theory (PET/ACT)	-Examined via single broadband measure (e.g., State-Trait Anxiety Inventory) -Model focuses on state anxiety to the neglect of trait anxiety	-Not directly assessed -Argues that effects of anxiety on working memory are a result of this component, but has been assessed via STAI (e.g., equated with trait anxiety)	-Not considered/ assessed	-Anxiety associated primarily with domain-general interference of working memory
Two Component Model	-Largely neglected -Examined in a later study (Vytal et al., 2016) with GAD patients; results conflicted with model	-Measured indirectly via participant self-report of distraction from, or preoccupation with, potential shock -Worry interferes with verbal working memory	-Directly explored and experimentally-induced through threat-of-shock paradigm -No self-report measures of arousal included -Arousal interferes with visuospatial working memory	-Anxiety associated with domain-specific interference of working memory: Anxious arousal associated with visuospatial working memory; -Worry associated with verbal working memory

Moran's (2016) proposed model	-Breaks anxiety into its subcomponents -“Common anxiety” variable combines variance from arousal and worry -Trait anxiety not uniquely measured	-Worry is uniquely linked to phonological working memory and also to domain-general attention via shared variance with arousal. -Not yet empirically tested	-Arousal is uniquely linked to visuospatial working memory and to domain-general attention via shared variance with worry. - Not yet empirically tested	-Anxiety associated with domain-specific and domain-general interference of working memory
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1984). However, while later work showed impaired performance on stressful cognitive tasks among individuals with high anxiety in comparison to those with low anxiety (e.g., measured as a categorical variable), such impaired performance was only reliably found when the cognitive task was difficult (e.g., greater processing or transient storage demands; Calvo, 1985; Eysenck, 1985). Such inconsistency led to the development of Processing Efficiency Theory (PET; Eysenck & Calvo, 1992), which is one of the most influential theories explaining the relationship between anxiety and reduced cognitive task performance (Moran, 2016). Proponents of PET argue that individuals with high anxiety are motivated to avoid aversive consequences—e.g., the consequence of poor task performance and negative evaluation by others should they avoid or escape the test situation (Eysenck & Calvo, 1992). Individuals with high anxiety are thus said to devote *increased* effort to cognitive task performance to avoid such consequences (Eysenck & Calvo, 1992).

PET distinguishes between *processing effectiveness* (e.g., accuracy on the cognitive task) and *processing efficiency* (e.g., the ratio of effectiveness on the task to effort and processing resources required to achieve such effectiveness) and argues that anxiety is associated with processing efficiency more so than processing effectiveness (Eysenck & Calvo, 1992). That is, individuals with high anxiety may achieve similar accuracy on cognitive tasks as those with low anxiety under many conditions, but such performance requires greater effort and resources to overcome the interference of anxiety and to turn cognitive processing toward the task at hand. To demonstrate this reduced processing efficiency, Hamilton (1978, as cited in Eysenck & Calvo, 1992)

asked participants with high and low anxiety³ to complete a digit span task while performing a secondary probe task which required an infrequent response to a probe stimulus. Despite being able to successfully recall the digit sequences, those with high anxiety were slower to respond to probes than those with low anxiety, suggesting the former group had less spare processing capacity. As can be seen, reduced processing efficiency often presents experimentally as increased response time (e.g., time required to utilize resources and strategies and overcome the effects of anxiety).

PET was designed primarily to explain the effects of state anxiety (referred to as “test anxiety” in this theory) on task performance, but also considers the role of trait anxiety. Eysenck and Calvo (1992) argue that an individual’s level of state anxiety in a performance situation is determined by an interaction between that individual’s level of trait anxiety and the level of situational stress or threat present. They argue that individuals with high trait anxiety tend to show greater state anxiety when presented with situational stress. PET also accounts for the multidimensional nature of anxiety—namely, that state anxiety (i.e., “test anxiety”) includes both worry and arousal components (Liebert & Morris, 1967). However, following from the empirical work of Deffenbacher (1980), PET concludes that the relationship of anxiety with cognitive performance is largely driven by worry (Eysenck & Calvo, 1992). Worry about evaluation may interfere with attention to task-relevant information, increase self-preoccupation, reduce cognitive resources available for task-related processing, and ultimately reduce the storage and processing capacity of the working memory system

³ Note, it was not clear from Eysenck and Calvo’s (1992) description of this study as to how the high and low anxiety categorical groups were derived.

available for the task (Eysenck & Calvo, 1992). Worry may, therefore, use some of the processing and storage resources of the working memory system prior to the cognitive task which requires such systems, and is thus associated with reduced task performance (Eysenck & Calvo, 1992).

PET assumes the phonological loop component of working memory may be implicated due to the phonological nature of worry (e.g., verbal rumination). However, worry is assumed to be most related to domain-general central executive performance, such that this component involves a control system that is sensitive to failure feedback about performance (e.g., that performance is falling below what is required or expected; Eysenck & Calvo, 1992; Eysenck et al., 2005). When such feedback is encountered, two potential responses of the central executive have been proposed, each resulting in improved task performance. Firstly, worry about task performance may encourage the central executive to allocate attention and effort to the task, and to initiate strategies to improve performance and avoid aversive consequences (e.g., poor performance, negative evaluation; Eysenck & Calvo, 1992; Eysenck et al., 2005). Alternatively, the central executive could also devote resources to cope with and reduce the experience of worry, thus freeing up working memory capacity (e.g., as a result of reduced interference from worry) and improving task performance (Eysenck & Calvo, 1992; Eysenck et al., 2005). PET ultimately argues that worry is associated with an increase in on-task effort and activities designed to improve performance, and thus is associated with impaired processing efficiency. Anxiety may also be associated with impaired processing effectiveness (i.e., accuracy) when tasks involve greater demands on the working memory system, and particularly so when involving substantial demands on the

central executive and phonological loop (e.g., under high task demands and difficulty; Eysenck & Calvo, 1992).

PET was later revised with the addition of Attentional Control Theory (ACT; Eysenck et al., 2007). This addition sought to address the effects of distracting stimuli on the cognitive performance of individuals with high anxiety and the potential interactions between anxiety and the type of stimulus involved in the cognitive task (i.e., threat-related versus neutral; Eysenck et al., 2007). These effects were not considered in the original theory and have been shown to be important in the study of cognitive performance and anxiety, such as in research on the attentional bias to threat in anxiety (e.g., Bar-Haim et al., 2007; Sass et al., 2010). ACT also aimed to address unclear aspects of PET, including *how* worry reduces processing efficiency, and which functions of the central executive are most affected by anxiety (Eysenck et al., 2007).

According to ACT, there are two attention systems: a *goal-directed* (i.e., top-down) *attentional system* which is driven by expectation, knowledge, and current goals (e.g., task-related goals); and a *stimulus-driven* (i.e., bottom-up) *attentional system*, which responds to salient stimuli in the environment (Eysenck et al., 2007). Anxiety's effects on cognitive performance are said to be the result of a disruption in the balance between these two attentional systems, such that there is a greater influence of the stimulus-driven system over the goal-directed system—for example, through the automatic processing of threat-related stimuli (Eysenck et al., 2005; Fox et al., 2001). To demonstrate this disruption, multiple studies (e.g., Markowitz, 1969; Shapiro & Johnson, 1987) have used a dual-task paradigm in which the secondary task stimuli were as salient or even more salient than those used for the primary task. The finding of those

studies revealed that participants categorized as high anxiety performed better on the secondary task than those categorized as low anxiety. These findings suggest that the stimulus-driven attentional system has more influence among those with high anxiety (Eysenck et al., 2005).

Anxiety is thus thought to impair processing efficiency on cognitive tasks as it reduces attentional control and interferes with the central executive task of *inhibition*, which results in increased distractibility in individuals with high anxiety (Eysenck et al., 2007). For instance, Pallak and colleagues (1975) used a Stroop task, where participants are required to name the ink color of a color word. On this task, participants generally show slower or less accurate performance when required to name the ink color of an incongruent color word (e.g., the word “red” written in blue ink) as compared to a congruent color word (e.g., the word “red” written in red ink). Pallak and colleagues (1975) induced anxiety among participants using a threat-of-shock paradigm and found that Stroop task performance was impaired by increased anxiety associated with impending shock, likely because of increased distractibility and impaired inhibition. Notably, while PET argued that anxiety impairs processing efficiency because it produces worry, ACT conceptualizes this more broadly by arguing that anxiety impairs the inhibition function and leads those with high anxiety to be more distracted by task-irrelevant stimuli, whether they are internal (e.g., worry thoughts) and/or external (e.g., neutral distractor in the environment; Eysenck et al., 2007).

In terms of the multicomponent model of working memory (Baddeley, 1986), PET/ACT thus argues primarily for *domain-general interference* of anxiety on working memory, such that deficits in terms of impaired processing efficiency and effectiveness

are argued to be the result of impaired functioning of the central executive component of working memory, and particularly of the *inhibition* function of this component (Eysenck & Calvo, 1992; Eysenck et al., 2005). It is assumed that there are only modest effects of anxiety on the domain-specific components of the multicomponent model, such as minor interference of worry on the phonological loop component of working memory (via, e.g., verbal rumination).

Limitations and Further Considerations of PET/ACT

More recent work provides mixed support for the claims of PET/ACT, specifically in terms of the predicted effects on performance efficiency relative to effectiveness. While some studies have found slower response time among those with higher anxiety when presented with irrelevant distractors as well as in the presence of increased perceptual load (Moser et al., 2012; Sadeh & Bredemeier, 2011), results from Spalding and colleagues (2021) revealed that a moderate level of anxiety was associated with faster correct responses (improved processing efficiency) in a more demanding working memory task compared to a less demanding one. This suggests that the presence of distracting information as well as task difficulty may be important factors in predicting effects on processing efficiency.

As well, studies supporting PET/ACT are limited by their coarse measurement of anxiety. While most consider both state and trait anxiety, anxiety is typically assessed with a single broadband measure of anxiety—namely, the State Trait Anxiety Inventory (STAI; Spielberger et al., 1983). Scores on a single measure of anxiety, however, may be obscured due to random error variance (e.g., that which arises during measurement) or systematic error variance (e.g., another construct, such as depression, is reliably but

unintentionally tapped into by the measure; Kim & Mueller, 1978; Watson et al., 1995). It is, therefore, important to utilize multiple measures of trait (or state) anxiety and its components to show a relationship at the construct level (Moran, 2016).

Previous research supporting PET/ACT has also failed to include distinct measures of the underlying components of anxiety—namely, worry and arousal (e.g., Eysenck & Calvo, 1992; Eysenck et al., 2005; Eysenck et al., 2007). While studies supporting PET/ACT argue that the main effects of anxiety are primarily a result of the worry component, these conclusions may be premature given that such studies do not distinctly assess worry and/or arousal, and instead rely solely on overall measures of state anxiety (e.g., the State-Trait Anxiety Inventory). Relatedly, the emphasis of this model is on worry in the context of state anxiety only. Given that worry has been shown to be a key experience within individuals with high trait anxiety, it is important to consider how PET/ACT accounts for the association between trait levels of worry and disrupted working memory performance.

PET/ACT also has several limitations in explaining the relationship between anxiety and working memory. First, while the PET/ACT theory suggests only a minor role for the phonological loop, studies examining this theory suggest there might be more of an effect than is accounted for by this model. Eysenck and colleagues (2005) tested PET in the context of the multicomponent model of working memory by having participants with high and low levels of trait anxiety complete a Corsi Blocks Test. In this task, participants view an experimenter while they tap a sequence on up to nine identical (spatially separated) blocks and are then asked to recall and repeat the sequence. Notably, the Corsi Blocks Test was designed to assess visuospatial working

memory (Berch et al., 1998; Corsi, 1972). Participants' working memory was tested with secondary concurrent tasks that involved either the phonological loop (i.e., an *articulatory suppression task*: repeating the letters A, B, C, and D out loud continuously), the visuospatial sketchpad (i.e., a *spatial tapping task*: tapping out a "z" pattern continuously), or the central executive (i.e., a *backwards counting task*: counting backwards by ones from a two-digit number, one number every second; Eysenck et al., 2005). While the primary results were in line with PET's conclusion of domain-general interference of anxiety on working memory (i.e., performing two concurrent tasks, which each required the central executive, led to unique decrements in performance among those with high anxiety), individuals with high anxiety performed worse than individuals with low anxiety on the Corsi test when concurrently completing the phonological secondary task. This latter finding was unexpected as the Corsi task is visuospatial in nature, is not reliant on the phonological loop, and thus should not be affected by a secondary phonological task. These results suggest effects of the phonological loop which are unaccounted for in the PET/ACT model. It may be beneficial to consider a similar design as Eysenck and colleagues (2005) but also to use a main task in which the phonological loop is required, to determine if combining such a main task with a secondary phonological task impairs performance among those with high anxiety more so than those with low anxiety.

Domain-Specific Interference: The Two Component Model

An alternative body of research has focused on the effect of experimentally-induced anxious arousal (i.e., threat-of-shock paradigms) on working memory performance. This research was initiated by findings from neuropsychological research and

electroencephalographic data suggesting that anxious arousal involves activation of the right prefrontal cortex and right posterior parietal cortex, areas of the brain that are also activated during performance of visuospatial working memory tasks (e.g., Shackman et al., 2006). Early research in this area suggested that this increased anxious arousal consistently disrupts visuospatial working memory due to shared neural resources and a limited ability to engage in top-down attentional control over such neural resources on account of their evolutionary survival advantage (Robinson et al., 2013a; 2013b). Verbal or phonological working memory task performance, on the other hand, was found to be unaffected by anxious arousal, or only impaired when tasks are not cognitively demanding enough to pull attention away from anxiety and toward task demands (Robinson et al., 2013a; 2013b; Shackman et al., 2006). Such dissociation continues to be supported by empirical studies (e.g., Bolton & Robinson, 2017).

Following this initial work, Vytal and colleagues (2012; 2013) proposed the Two Component Model to explain how anxiety affects working memory. The Two Component Model supports the distinction between *anxious arousal* and *worry* in an anxious response. They add to this distinction, however, by arguing that anxious arousal involves an automatic preparatory response that primes defensive mechanisms (from evolutionary theory), is not amenable to top-down attentional control, persists across all levels of task difficulty, and is particularly affected in spatial working memory tasks. In contrast, worry is argued to engage executive resources and is amenable to top-down attention control (Vytal et al., 2012; 2013). Additionally, worry is said to affect verbal working memory variably depending on the level of task difficulty, with impaired performance most likely to occur on tasks of low difficulty, while under high task

difficulty (e.g., when cognitive load and attentional demands were high), task performance takes precedence over worry, and performance is improved (Vytal et al., 2012).

Apparent support for the Two Component model's account of the worry component of anxiety comes from studies implementing the threat-of-shock paradigm, which has been shown in the past to primarily elicit the arousal component of anxiety (Moran, 2006; Shackman et al., 2006; Robinson et al., 2013a; b). To consider the effects of worry in this context, Vytal and colleagues (2012) measured worry indirectly by asking participants to retrospectively rate how distracted or cognitively disengaged they were from the shock on a given set of trials. Thus, worry was measured in terms of a 'state' experience in this study, regardless of participants' trait levels of worry. Ratings of greater distraction or disengagement were taken as evidence of increased worry in the study, such that worry involves preoccupation with and attention to the object of worry (shocks in this case; Vytal et al., 2012). Results were in line with the Two Component model, such that heightened state levels of worry impaired performance on tasks of low difficulty, while under high task difficulty (i.e., when cognitive load and attentional demands were high), task performance took precedence over anxiety-related cognitive processing (i.e., worry), and performance was improved (Vytal et al., 2012). Vytal and colleagues (2013) provided further support for the Two Component Model. Specifically, in their work, threat-of-shock-induced anxiety disrupted performance on the verbal working memory task under low and medium cognitive load but not high cognitive load. In contrast, this induced anxiety disrupted performance on spatial working memory across *all* levels of cognitive load.

Limitations and Further Considerations of the Two Component Model

Although the Two Component Model accounts for both arousal and worry, the model largely explains heightened *state anxiety* (via threat-of-shock paradigms). Trait anxiety, on the other hand, is largely neglected in these explanatory models. In a later study by Vytal and colleagues (2016), the effects of trait anxiety were examined more explicitly. In that study, individuals with Generalized Anxiety Disorder (GAD), who characteristically show high trait anxiety and pathological worry, along with healthy control participants, completed a verbal working memory task while under the threat of shock (i.e., induced heightened state anxiety). Results revealed impaired performance among those with GAD when under threat regardless of task difficulty, which differed from the performance of healthy controls and ultimately conflicted with predictions of the Two Component Model (i.e., that state anxiety should only impair verbal working memory performance under low-load conditions; Vytal et al., 2012; 2013). Instead, when performing a highly demanding and difficult task (e.g., with high cognitive load) under threat, GAD patients appear to devote cognitive resources to reducing anxiety rather than focusing on the task to facilitate performance (Vytal et al., 2016). The inconsistency suggests that there are unique effects of trait anxiety that are not adequately accounted for in the Two Component Model. Furthermore, these results suggest that task difficulty may be less important in predicting working memory task performance among those with heightened trait anxiety (e.g., those with GAD).

Vytal and colleagues' (2016) approach to examining trait anxiety may be limited, however. The observed inconsistency for GAD patients observed by Vytal and colleagues may not necessarily be representative of individuals with high trait anxiety

more broadly (i.e., without a diagnosis of GAD). Individuals with GAD are characterized not only by excessively high levels of trait anxiety but by pathological levels of worry as well as cognitive biases and unique experiences that do not appear to be considered in this research (APA, 2013; Clark & Beck, 2010; Newman & Llera, 2011). As a specific example, individuals with Generalized Anxiety Disorder often have positive beliefs about worry (Clark & Beck, 2010), such as believing that worry helps them to be emotionally prepared for the worst possible outcome to various events and is thus a useful compensatory strategy (Newman & Llera, 2011). Accordingly, the association between heightened trait anxiety and working memory performance should be further explored and may not be best represented by *solely* considering individuals with GAD. The current study will consider working memory performance among individuals with high trait anxiety more broadly—that is, within a university sample of individuals with high trait anxiety but not necessarily a GAD diagnosis. This may better elucidate the role of trait anxiety in this context rather than other potentially influential clinical characteristics of GAD.

Much like with PET/ACT studies, there are notable limitations to how anxiety is assessed in studies examining the Two Component Model. This includes broad subjective ratings of anxiety (e.g., the State-Trait Anxiety Inventory), as well as lack of direct assessment of the subcomponents of worry and arousal. While previous studies in this area suggested that anxious arousal more robustly impairs spatial working memory than verbal working memory, the potential effects of worry in this context are neglected. Worry could in fact be the key component of anxiety that interferes with verbal working memory (as argued by PET/ACT; Eysenck & Calvo, 1992; Eysenck et al., 2007; Moran,

2016) and may not be reliably elicited in these previous studies using the threat-of-shock paradigm. If worry is not reliably present among participants in these previous studies, interference with verbal working memory may also be unreliable, thus obscuring effects of anxiety on verbal working memory performance.

While the aforementioned studies have been said to reliably induce anxious arousal using the threat-of-shock paradigm, a noted criticism of the previous literature in this area is that trait levels of arousal—that is, the tendency to *regularly* experience symptoms of arousal (e.g., shortness of breath, dizziness, shaky hands, dry mouth) across a number of situations—is seldom examined directly (Moran, 2016). Taken together, these limitations highlight several considerations for future work examining the Two Component Model.

The literature appears to be limited in our understanding of the relationship between trait levels of arousal and worry with visuospatial and verbal working memory. While the Two Component Model argues that anxiety is a strong predictor of threat-related working memory impairment and that higher cognitive loads affect verbal task performance differently than spatial because of the verbal nature of anxiety (namely, the worry component), it is currently difficult to say whether worry, anxious arousal, or both components of anxiety are predictive of working memory impairment. Finally, while proponents of the Two Component Model attempt to explain domain-*specific* interference of anxiety on working memory (i.e., unique effects of arousal and worry on verbal and spatial working memory, respectively), they neglect to consider domain-*general* interference, which is important according to Moran's (2016) review as well as the research on inhibition and filtering efficiency (e.g., Stout et al., 2013; 2015).

Resolving the Debate? Moran's (2016) Proposed Theory

Moran (2016) proposed a comprehensive model (also summarized in Table 1) which combines the major tenets of the PET/ACT and the Two Component models. Moran's model emphasizes the complexity of the relationship between anxiety and working memory and incorporates many of the key variables noted in previous research in this area. In this model (See Figure 2), it is assumed that the processes associated with worry and arousal are linked to interference and reduced performance of working memory components—the phonological loop and the visuospatial sketchpad, respectively—due to the anxiety and working memory components relying on the same underlying processes. However, Moran (2016) also noted how worry and arousal predict working memory capacity more broadly. He argued there is shared variance between worry and arousal (i.e., *common anxiety*) that is not accounted for in the effects on the storage components. This common anxiety is associated with impaired functioning of the central executive (i.e., the domain-general control of attention and working memory) including abilities such as inhibition, switching, and updating. To date, Moran's model has not been empirically tested.

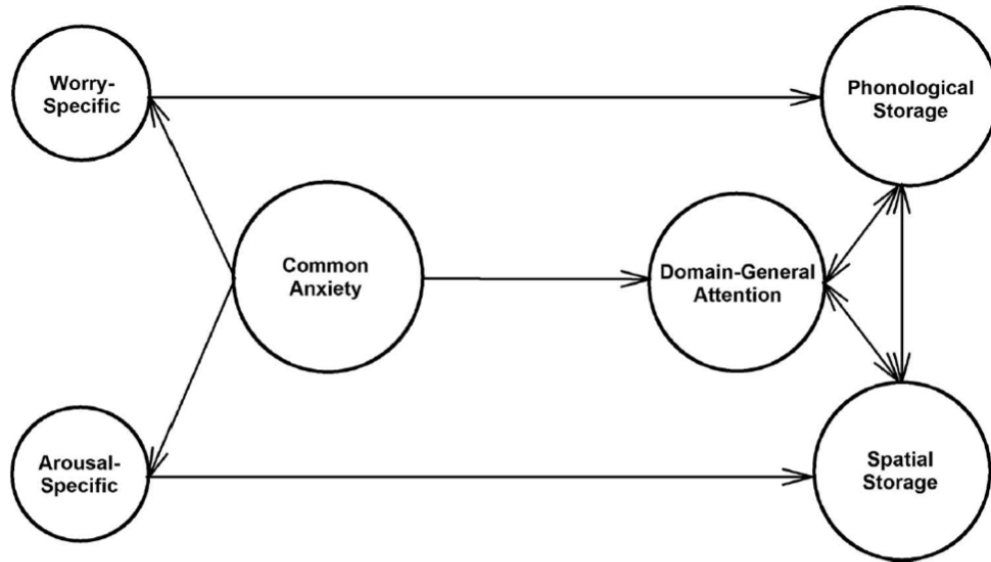


Figure 2. Potential model of the relationship between anxiety and working memory as proposed by and presented in the Moran (2016) review.

Current Study: Research Questions and Contributions

The current study aimed to resolve noted limitations and inconsistencies of past research (such as those identified by Moran, 2016) examining the anxiety and working memory relationship. This was done by considering (a) trait anxiety, (b) both arousal and worry components of trait anxiety, (c) both verbal and visuospatial working memory, (d) the role of baseline working memory storage capacity and (e) the role of threat. I focused on the effects of *trait* anxiety on working memory, as this domain has been largely neglected in comparison to considerations of *state* anxiety and has shown unique and unexpected relationships to working memory performance when considered (Moran, 2016; Vytal et al., 2012; 2013; 2016). Participants in the current study were asked to complete self-report questionnaires assessing arousal and worry. It is important to note that each of the anxiety variables in the current study were continuous in nature. Worry and Arousal were defined as continuous scores on the Penn-State Worry Questionnaire and the Trait Arousal subscale of the State Trait Inventory of Cognitive and Somatic Anxiety. Overall Trait Anxiety scores were computed by summing Worry and Arousal scores for each participant. These compound scores provide information over and above the individual subcomponent scores. For example, a high compound score could reflect a high worry score and a moderate arousal score. Or the identical compound score in another individual could reflect a moderate worry score and a high arousal score. Compound trait anxiety scores are useful in the current study to give an indication of how overall trait anxiety may be uniquely associated with working memory. Using compound Trait Anxiety scores also corresponds to the typical

measurements used in previous research in this area—namely, using broadband measures that include items assessing underlying symptoms of worry and arousal.

Working memory was primarily operationalized via *filtering efficiency*, which is a measure of domain-general attention and central executive functioning within working memory (i.e., the ability to inhibit irrelevant or distracting information from gaining access to working memory to perform a cognitive task; Vogel et al., 2005). Following from assumptions from PET/ACT (Eysenck et al., 2007), participants' response time was considered an indicator of how quickly and easily participants make accurate judgments on the filtering efficiency task. Thus, RT in the current study was used to infer *processing efficiency*—how *efficiently* individuals with varying levels of trait anxiety are able to process information in working memory and make an accurate response. The overall goal of the current study was to make crucial advances toward elucidating the underlying mechanisms of the trait anxiety and working memory relationship and to provide support for one or more explanatory models of this relationship.

Participants were asked to complete phonological and visuospatial versions of a baseline working memory storage capacity task (i.e., simple change detection) and a filtering efficiency (complex change detection) task. In the complex task, participants were asked to study target stimuli, while ignoring or filtering non-target (i.e., distractor) stimuli. The presence of distractor stimuli and the emotional valence of such stimuli (emotionally neutral or threatening in nature) were considered. To examine domain-specific (i.e., phonological and visuospatial) storage *and* domain-general interference, I employed tasks using visuospatial stimuli (i.e., faces as in previous research; Stout et al.,

2013; Stout et al., 2015) or phonological stimuli (i.e., short words; this is a novel task that I developed for the current work). Although task difficulty has been considered earlier during the examination of the Two Component Model (Vytal et al., 2012; 2013) and is worthy of future work, I did not consider this factor in my project. The focus of the current project was on better understanding the relationship between heightened trait anxiety and both phonological and visuospatial working memory and, as a result, a task difficulty manipulation was outside the scope of my proposed work. My project examined the relationships among overall trait anxiety, arousal, and worry; stimulus type (i.e., phonological or visuospatial); baseline working memory capacity; and filtering efficiency of irrelevant threatening and neutral distractors.

The proposed research sought to answer 4 research questions (see Table 2). I examined support for the PET/ACT and Two Component Model accounts of the anxiety and working memory relationship when working memory was operationalized as: filtering efficiency (**Research Question 1**); baseline working memory storage capacity (**Research Question 2**); and processing efficiency (**Research Question 4**). As well, I examined whether baseline storage capacity, in terms of simple change detection task performance, moderated the relationships between the anxiety variables (Arousal, Worry, Trait Anxiety) and filtering efficiency (i.e., complex change detection task performance), for each of the two types of stimuli included in the working memory tasks (i.e., phonological and visuospatial; **Research Question 3**). While examining the anxiety and working memory relationship in the context of filtering efficiency was my primary goal (i.e., Research Question 1), Moran (2016) concluded that anxiety is associated with impaired cognitive task performance even when tasks do not require

Table 2. Summary of research questions

<i>Filtering Efficiency</i>	RQ1	Is the relationship between anxiety and reduced filtering efficiency better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT) or the domain-specific interference account of the Two Component Model? Or, are the two accounts complementary to one another?
<i>Baseline working memory storage capacity</i>	RQ2	Is the relationship between anxiety and baseline working memory storage capacity better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT) or the domain-specific interference account of the Two Component Model? Or, are the two accounts complementary to one another?
	RQ3	Does anxiety (e.g., worry, arousal, and/or trait anxiety) moderate the relationship between baseline working memory storage capacity and filtering efficiency, depending on the type of stimuli included in the working memory tasks (e.g., phonological or visuospatial)?
<i>Response time (Processing Efficiency)</i>	RQ4	Is the relationship between anxiety and longer response times (e.g., reduced processing efficiency) better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT) or the domain-specific interference account of the Two Component Model? Or, are the two accounts complementary to one another?

inhibition, which may point to impaired performance of the storage components of working memory (e.g., the phonological loop and/or visuospatial sketchpad) rather than the central executive, thus underscoring the value of Research Question 2. As well, examining processing efficiency or participants' response time to accurately detect changes on baseline trials of the change detection task in which there are no distractors present, allows for consideration of *how easily* individuals with varying levels of anxiety can temporarily store phonological and visuospatial information in working memory to complete a cognitive task (e.g., detect changes in this stored information; Eysenck et al., 2007). Research Question 4 thus sought to examine potential relationships between anxiety and processing efficiency.

To examine **Research Questions 1 and 2**, I compared model fit of linear mixed effects (LME) models, corresponding to each of the three continuous measures of anxiety (i.e., Arousal, Worry, and Overall Trait Anxiety). For Research Question 1, there were two criterion variables: filtering cost for the phonological task and for the visuospatial task. The three models were compared in terms of their relative contributions in predicting filtering task performance. Research Question 2 considered baseline working memory task performance (i.e., accuracy on a working memory task which does not require filtering), and there were again two criterion variables: baseline task performance for the phonological task and for the visuospatial task. The current state of the literature examining the anxiety and working memory relationship provides ample evidence in favor of both the domain-specific and domain-general interference accounts. As such, I did not have specific predictions for which model(s) would prove most influential through the results of my dissertation. Instead, the key goal was to

execute a study that was designed to further adjudicate between these accounts and to determine which account would best explain the data. With that said, several outcomes were theoretically plausible, and each would further our understanding of this complex relationship between anxiety and working memory. Specifically, if the data supported the Two Component Model, then I expected the Worry model would better fit the phonological data than the Arousal model, while the Arousal model would better fit the visuospatial data than the Worry model. This would underscore the unique interference between worry and phonological working memory and between arousal and visuospatial working memory (i.e., domain-specific interference). If the data supported Processing Efficiency Theory/Attentional Control Theory, then I expected that the Overall Trait Anxiety would provide the best fit of both the phonological and visuospatial filtering cost data, above and beyond the Arousal and Worry models. This would suggest a more general relationship between anxiety and working memory which is not unique to worry and/or arousal levels nor to phonological versus visuospatial working memory (i.e., domain-general interference). If both outcomes were observed (i.e., Overall Trait Anxiety model > Worry model > Arousal model for the phonological data; Overall Trait Anxiety model > Arousal Model > Worry model for the visuospatial data), then this would support Moran's (2016) model, and suggest a role for both domain-specific and domain-general interference in the relationship between anxiety and working memory.

Notably, for Research Question 1, I expected that Distractor Type would interact with anxiety in the three models, based on evidence that individuals with high anxiety show an attentional bias to threat-related stimuli and this interferes with cognitive task performance (Bishop et al., 2007; Stout et al., 2015). However, the involvement of that

variable in the models was of less importance to the evaluation of the Two Component model or the PET/ACT model.

Research Question 3 asked: *Does anxiety (i.e., worry, arousal, and/or trait anxiety) moderate the relationship between baseline working memory storage capacity and filtering efficiency, depending on the type of stimuli included in the working memory tasks (i.e., phonological or visuospatial)?* I examined whether baseline storage capacity, in terms of simple change detection task performance, moderated the relationships between the anxiety variables (Arousal, Worry, Trait Anxiety) and filtering efficiency (i.e., complex change detection task performance), for each of the two types of stimuli included in the working memory tasks (i.e., phonological and visuospatial). Various studies have suggested that anxiety interacts with working memory span to influence cognitive task performance (e.g., Stout & Rokke, 2010; Qi et al., 2014). Unfortunately, later studies in this area which examined the effect of anxiety on filtering efficiency in change detection tasks did not include a baseline measure of storage capacity (i.e., Stout et al., 2013; 2015). As such, this research question was exploratory and was meant to contribute to delineating any relationships that may exist.

Similar to Research Questions 1 and 2, to examine **Research Question 4**, I compared model fit of linear mixed effects (LME) models, corresponding to each of the three continuous measures of anxiety (i.e., Arousal, Worry, and Overall Trait Anxiety) in explaining processing efficiency (i.e., response time) for phonological and visuospatial working memory tasks. As with Research questions 1 and 2, I did not have specific predictions for which model(s) would prove most influential in explaining processing efficiency results, as ample research has supported both the domain-specific

and domain-general accounts. Instead, the key goal was to further adjudicate between these accounts and to determine which account would best explain the data.

Method

Participants

Undergraduate students (N=64) from the University of New Brunswick were recruited for the current study from the psychology participant pool, in exchange for psychology course credit. Four participants were excluded from analyses due to chance-level performance on one or more conditions within the working memory tasks, resulting in a final sample of 60. Participation was limited to individuals under age 60 due to the noted declines in cognitive abilities, including working memory, among older adults (e.g., Craik & Salthouse, 2000; Gazzaley et al., 2005). The target sample size of the current study was determined via recommendations of Brysbaert and Stevens (2018). Determination of adequate power for Linear Mixed Effects models (the key statistical approach in the current study) typically involves the use of *simulations*, as discussed in Brysbaert and Stevens (2018). Performing such simulations requires information from pilot data or from the literature regarding the effects that are under investigation (e.g., proportion of variance accounted for by each predictor variable) in the current dissertation. Unfortunately, this information was not available. Brysbaert and Stevens (2018) alternatively recommend a sample size sufficient to produce at least 1600 data points per condition, where the number of data points is equal to the number of participants multiplied by the number of trials in each experimental condition. In the current study, there were a total of 8 conditions of interest in the key statistical analysis:

4 Trial types (Baseline, Neutral Target, Neutral Distractor, Threat Distractor) x 2 Stimulus Types (visuospatial, phonological). For each of these 8 conditions, there were 96 trials. With 60 participants, this results in 5760 data points per condition (i.e., 96 trials per condition x 60 participants), thus exceeding the recommendations of Brysbaert and Stevens (2018). Although a smaller N (e.g., N=20) would be sufficient to meet the recommendations of these researchers, a larger N was sought to encourage sufficient variability in the anxiety variables of interest in the current study.

Measures and Tasks

Trait Worry. The 16-item self-report Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990) was used to assess trait levels of worry, in terms of its excessiveness, duration, uncontrollability, and associated distress. Each item is rated on a 5-point scale (1=Not at all typical of me; 2=Rarely typical of me; 3=Somewhat typical of me; 4=Often typical of me; 5=Very typical of me). Example items include: “My worries overwhelm me”, “I am always worrying about something”, and “I have been a worrier all my life”. Total worry scores are computed by summing the scores for each of the 16 items, and scores can range from 16 to 80, with higher scores indicating greater levels of worry. Total worry scores in the current study ranged from 18 to 77 ($M = 57.82$, $SD = 13.13$). The Penn State Worry Questionnaire has shown strong reliability (e.g., internal consistency $\alpha = .94$) and validity in several investigations (Hazlett-Stevens et al., 2004; see Molina & Borkovec, 1994 for review). The PSWQ has also shown strong positive correlations (e.g., $r = 0.62$) with the Trait subscale of the State-Trait Anxiety Inventory (STAI; e.g., Nitschke et al., 2001).

Trait Arousal. The Trait Somatic subscale of the State Trait Inventory of Cognitive and Somatic Anxiety (STICSA; Ree et al., 2000) was used to examine trait levels of arousal symptoms. This includes 11 items (e.g., “My heart beats fast”; “My breathing is fast and shallow”; “I have butterflies in my stomach”) that ask participants to indicate how often, in general, each statement is true of them. Each item is rated on a 4-point scale (1=Not at all; 2=A little; 3=Moderately; 4= Very Much So). Total trait arousal scores were calculated by summing the scores across the 11 items. Scores can range from 11 to 44, with higher scores indicating higher trait levels of anxious arousal. Total arousal scores in the current study ranged from 14 to 39 ($M = 24.45$, $SD = 5.87$). The 4 subscales of the STICSA, including the Trait Somatic scale utilized in the current study, have demonstrated good internal consistencies (alphas $>.92$; Roberts et al., 2016). The STICSA has also shown evidence of adequate convergent and divergent validity, and it has been suggested that the STICSA may in fact be a purer measure of anxiety than the State Trait Anxiety Inventory as scores on the former are less highly correlated with scores on measures of depression (i.e., the Beck Depression Inventory) than the latter (i.e., r 's = .42 - .59 for the STICSA versus $r = .68$ for the STAI-Trait; Grös et al., 2007; Roberts et al., 2016).

Overall Trait Anxiety. A composite score was computed to determine overall trait anxiety levels of each participant. This involved summing each participant's score on the Trait Worry (i.e., Penn-State Worry Questionnaire) and Trait Arousal (State Trait Inventory of Cognitive and Somatic Anxiety- Trait arousal subscale) measures. Such an approach was selected to best represent the model of trait anxiety tested in the current study—namely a 2-component model including worry and arousal. Inclusion of the

composite “overall trait anxiety” variable allows for examination of common variance between arousal and worry, which Moran (2016) argues plays a unique role in the anxiety and working memory relationship (see Figure 2). The possible range of the composite score can thus range from 32 to 121. Total trait anxiety scores in the current study ranged from 34 to 114 ($M = 82.27$, $SD = 17.13$).

Notably, several valid trait anxiety measures exist, including the State Trait Anxiety Inventory (Spielberger et al., 1983) and the State Trait Inventory for Cognitive and Somatic Anxiety (Ree et al., 2000). However, the STAI Trait form appears to be a better measure of worry than arousal, as evidenced by stronger correlations between the STAI-T and the Penn-State Worry Questionnaire ($r = 0.62$) than the Anxious Arousal subscale of the Mood and Anxiety Symptom Questionnaire ($r = 0.36$; Nitschke et al., 2001). The STAI trait form also does not appear to adequately assess trait arousal symptoms and may not reflect a “pure” anxiety measure (Bieling et al., 1998; Nitschke et al., 2001). The STICSA’s Cognitive subscale assesses cognitive symptoms associated with the experience of worry (e.g., intrusive thoughts and issues with concentration; Ree et al., 2000), but beyond the scope of the actual act of worry as defined in this study (e.g., verbal rumination and preoccupation with potential negative outcomes of future events). As such, existing measures of trait anxiety do not meet the needs of the current study and it was decided that trait anxiety would be better represented as a composite score.

Baseline working memory storage capacity. Participants’ baseline working memory capacity—in the absence of any need for filtering—was examined with a simple change detection task. Two unique sets of neutral stimuli were used: faces (i.e.,

visuospatial stimuli) and words (i.e., phonological stimuli). Refer to Appendix A (p. 126) for a list of the facial stimuli selected from the Karolinska Directed Emotional Faces database (KDEF; Lundqvist et al., 1998). I selected 12 unique models (6 male) displaying neutral facial expressions. Stimuli were selected on the basis of displaying a Caucasian model and being uniform in background lighting. For the word stimuli, I created a list of 12 short words (i.e., between 3 and 5 letters) which are neutral in valence (See Appendix B, p. 127). Valence ratings for all words were obtained from Warriner and colleagues (2013) which presents average valence ratings for over 13,000 English words. Valence ratings of all words in this database range from 1 to 9 with lower values indicating a negative valence and higher values indicating a positive valence (Warriner et al., 2013). The neutral words selected for the current study had valence ratings between 5.08 and 6.77, with an average rating of 5.73.

In the visuospatial change detection task, a bilateral display was used, producing 4 quadrants (i.e., upper-right, upper-left, lower-right, lower-left) and allowing for presentation of up to four stimuli on a given trial. On each trial, 1 to 4 items were presented, and their locations were randomly selected; however, on each trial, study and test displays used the same number and locations for stimuli. To begin each trial, participants viewed a brief fixation point (i.e., a plus sign) that was positioned in the center of the screen. This fixation point remained in this central position for the entirety of each trial. Following brief presentation of the fixation point on its own (i.e., 500 ms), a study array (e.g., 1-4 faces outlined by black boxes) was presented and participants were instructed to attend to and remember all stimuli presented in this array. Then, participants were presented with a test stimulus array and were asked to determine

whether a change occurred from the study array. On 50% of trials, a change occurred such that one of the study array stimuli was replaced by another neutral stimulus within the test array. The replacement stimulus was randomly selected from the neutral stimulus set. The change detection task has been well-studied as a measure of visuospatial working memory capacity, and has been shown to be robust to verbal contamination—that is, participants have been shown to be unlikely to use verbal coding strategies when presented with visuospatial stimuli within this context (e.g., Vogel, Woodman, & Luck, 2001). Given the low likelihood of verbal contamination and because Stout et al. (2013; 2015) did not use an articulatory suppression task, no articulatory suppression task was used in the current study.

For the phonological change detection task, a novel task was developed for the current study. While there are many well-known and well-validated tasks to assess verbal working memory (e.g., span tasks, n-back task, see Owen, MacMillan, Laird, & Bullmore, 2005; Redick et al., 2012), a key goal of the current study was to examine filtering efficiency, and the aforementioned tasks do not involve a filtering component. Moreover, while such established tasks may have been modified to include a filtering component, it was my intention to obtain working memory tasks that are as parallel as possible (to allow better comparison across tasks). Thus, I decided that modifying the visuospatial change detection task utilized within the anxiety and filtering efficiency literature (i.e., Stout et al., 2013; 2015) with phonological stimuli would best serve this purpose. Several steps were taken to encourage the validity of this novel task, including review of previous literature to determine crucial factors to consider in task development (e.g., presentation format, length of presentation) and pilot testing of the task to

determine its feasibility as well as to examine whether verbal/phonological strategies were used.

Thus, for the phonological task, sequential presentation was used instead of the simultaneous presentation format used in the visuospatial task. Initially, it may seem that using the same format as will be used for the visuospatial task (but with words as stimuli) would suffice to examine phonological coding. However, a major concern emerges regarding using such an analogous approach. First, if words are presented in such a visuospatial array, participants could code the word information visually (e.g., based on the visual characteristics of the letters/words) or based on a phonological recoding of those words. For the current work, it was crucial that phonological coding be used. However, previous work by Pegado and Grainger (2020) has suggested that such simultaneous presentation of word stimuli is more likely to give rise to visuospatial coding. Those researchers also note that sequential presentation may be more likely to give rise to phonological recoding of those stimuli. Notably, other phonological tasks such as those utilized in research examining the phonological loop and articulatory suppression (e.g., Murray, 1968; Norris et al., 2018), as well as the task utilized by Pegado and Grainger (2020), have used sequences of verbal material presented visually to tap into phonological working memory performance. Although auditory presentation of verbal stimuli also taps phonological working memory (Baddeley et al., 1979), this presentation format does not easily lend itself to the modifications needed for a filtering efficiency version of the task.

For the phonological variant of the change detection task, the following procedure was used. On each trial, 1 to 4 items (outlined in black boxes) were presented,

and their order was randomly selected; however, study and test displays used the same number and order for stimuli. To begin each trial, participants viewed a brief fixation point (i.e., a plus sign) at the center of the screen for 200-400 milliseconds. Following this, a study set of 1 to 4 words was presented sequentially, with each word presented for 250 milliseconds. Participants were instructed to attend to and remember all stimuli presented. Then, participants were presented with a test stimulus set—where stimuli were again presented sequentially—and were asked to determine whether the stimuli from the study set were the same as those in the test set or whether a change had occurred in one of the sequentially presented stimuli. Due to the novel nature of this phonological version of the change detection task, pilot testing was conducted to ensure the validity and feasibility of this approach. Such pilot testing sought to determine the appropriate length of presentation of each stimulus in the sequential presentation (e.g., whether 250, 500 or 1000 milliseconds is most feasible), along with the most effective set size variation to obtain variable performance on this task (e.g., 2-6 words to-be-remembered instead of 1-4) and the difficulty of detecting changes with word stimuli. For set sizes and stimulus duration, I sought to determine a subset of set sizes (and a stimulus duration) that ensures variability in performance across participants. In one of the original studies with a visuospatial change detection task, Vogel and colleagues (2005) found ceiling effects in performance for small set sizes (e.g., set size = 1), and decreasing performance with increasing set size. While it was not important for the phonological task performance of participants in the current study to be identical to that of the visuospatial task, I used pilot testing of the phonological task to ensure that participants' responses did not exhibit ceiling and/or floor effects at all set sizes (e.g.,

100% performance at all set sizes would suggest the task is too easy, whereas 50% performance at all set sizes would suggest the task is too difficult and participants guessed when making their responses). I sought to determine the appropriate duration to allow for variability in performance, such that the average performance across set sizes was approximately 80%. This target value is better than chance (i.e., 50%) and allows for variability in performance across set sizes (e.g., with better performance for smaller set sizes and vice versa), while reducing ceiling and floor effects. Results of the pilot testing revealed decreasing accuracy with increasing set size, as expected given increasing demands on working memory with a greater number of items to remember. Moreover, results indicated that a subset of set sizes ranging from 2 to 5, along with a stimulus duration of 250 milliseconds, would allow for variability in performance and thus examination of baseline verbal working memory capacity. Results and further discussion of pilot testing can be found in Appendix C.

Inhibition and filtering efficiency. A lateralized change detection working memory task adapted by Stout and colleagues (2015) was used to estimate filtering efficiency (i.e., the ability to effectively access working memory while gating task-irrelevant distractor stimuli) of threatening and neutral stimuli. Stimuli consisted of faces (i.e., visuo-spatial stimuli) and words (i.e., phonological stimuli). Facial stimuli included the same 12 models (6 male) used in the simple change detection task. However, both neutral facial expressions (i.e., the same as used in the previous task) and threatening facial expressions (i.e., half fear; half angry) were utilized from these 12 models (See Appendix A). Similarly, the neutral word stimuli from the simple change detection task were matched with negative words to create a list of short word pairs.

Valence ratings of the negative words were also obtained from Warriner and colleagues' (2013) database. The negative stimuli selected for the current study had valence ratings ranging from 1.81 to 4.38, with an average rating of 2.96. Word pairs were matched on several psycholinguistic variables using ratings from the MRC Psycholinguistic Database (Coltheart, 1981). This included matching on verbal frequency, written frequency, familiarity, concreteness, and imageability⁴. See Table 3 for descriptive data of the ratings. Paired samples *t*-tests⁵ revealed no significant differences between negative and neutral words on any of the psycholinguistic variables: Written frequency $t(19)=-1.121, p=.276$; Verbal frequency $t(19)=-1.569, p=.133$; Concreteness $t(19)=-1.516, p=.146$; Familiarity $t(21)=-0.340, p=.738$; Imageability $t(19)=0.202, p=.842$. Words were also matched on the number of letters and syllables, ranging from three to five letters and one to three syllables. Paired samples *t*-tests revealed no significant differences between negative and neutral words on number of letters, $t(19) = 0, p = 1.00$, or on number of syllables, $t(19) = -0.37, p = .716$. The complete list of words can be found in Appendix B (p. 127).

For the visuospatial filtering efficiency task, the same bilateral display from the visuospatial simple change detection task was used. A visual depiction of the visuospatial version of the task in the current study can be found in Figure 1. On each

⁴As per the MRC Psycholinguistic Database, Written Frequency ratings for all words in the English language range between 0 and 69971, Verbal Frequency between 0 and 6833, and concreteness, familiarity and imageability each between 100 and 700. All words (i.e., neutral and negative) selected for the current study were relatively infrequent (Written Frequency ratings between 1 and 200; Verbal Frequency between 1 and 51) and were moderately to highly concrete (ratings between 200 and 650), familiar (ratings between 400 and 650), and imageable (ratings between 300 and 650).

⁵ Paired samples *t*-tests are used in this case as each neutral word was matched with a negative word on the psycholinguistic variables to create word-pairs.

Table 3. Descriptive statistics of psycholinguistic data for the word stimuli.

	Minimum Rating		Maximum Rating		Mean		Standard Deviation	
	Neutral	Negative	Neutral	Negative	Neutral	Negative	Neutral	Negative
Verbal Frequency	1	1	57	51	13.05	8.35	15.93	11.36
Written Frequency	4	7	283	187	75.2	60.45	64.4	48.11
Concreteness	259	244	606	612	401.95	372.6	86.31	105.38
Familiarity	503	460	625	600	552.05	549.1	31.69	28.8
Imageability	319	323	610	634	442.75	446.75	82.18	88.88

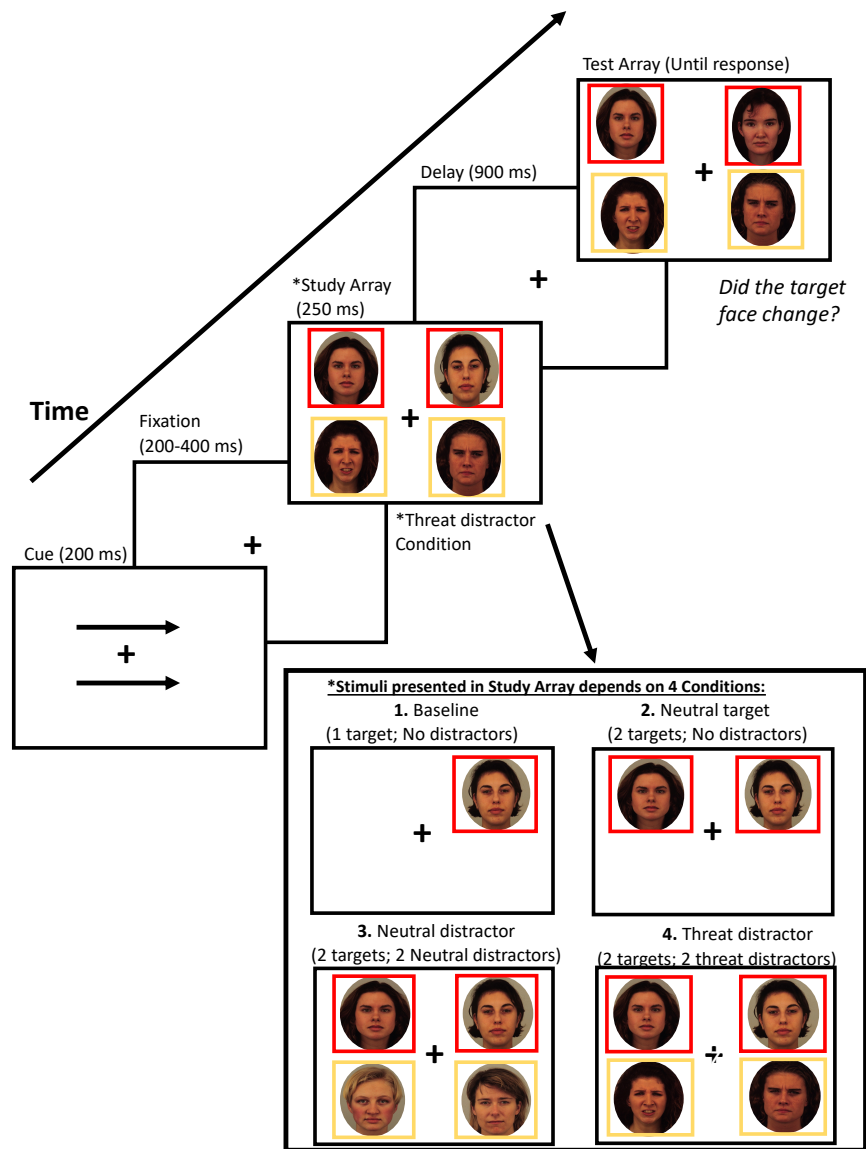


Figure 1. Visual depiction of the filtering efficiency task utilized by Stout and colleagues (2013; 2015).⁶

⁶ Facial stimuli for this sample display were selected from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist et al., 1998) and include the following stimulus codes: AF29NES, AF17NES, AF28NES, AF31NES, AF08ANS, AF13ANS

trial, participants viewed a fixation point that was briefly presented alone at the center of the screen and remained throughout the trial. Participants were cued to one hemifield by two arrow cues (e.g., both pointing either to the left or to the right), one below the fixation point and one above. Such arrows indicated the to-be-remembered target stimuli for the trial and were counterbalanced within participants (e.g., participants were cued to the right for half of trials and were cued to left for the remainder of trials). Although the direction of the arrow cue was randomly chosen on each trial, equal proportions of left- and right-pointing arrow cues were used over the course of the experiment. The arrow cues were presented for 200 milliseconds, followed by the fixation cross presented alone for 300 milliseconds. Next, the study array was presented for 250 milliseconds. Within each study array, stimuli were outlined in one of two colors (e.g., red or yellow), corresponding to target and distractor images. Participants were instructed to attend to and remember target images outlined in one color (e.g., red) while ignoring images outlined in the other color (e.g., yellow).

For the visuospatial filtering efficiency task, the target and distractor colors were counterbalanced across participants (e.g., between-subjects). Target stimuli were always models displaying neutral facial expressions. Within cued stimuli (e.g., faces in the cued hemifield), one target face was presented alone or alongside a distractor face. Thus, participants were cued to remember a single target face on each trial—that which was cued *and* outlined in the appropriate color. Following the presentation of the study array, there was a 900-millisecond delay interval during which the fixation cross was presented alone and the target must be maintained in working memory. Finally, the test array was

presented until response, and participants were asked to indicate via key press whether the target changed.

To examine the influence of distractor stimuli as well as the emotional valence of stimuli on filtering efficiency, four conditions were used: baseline, neutral target, neutral distractor, and threat distractor. The example in Figure 1 illustrates a case in which the target color is red and the distractor color is yellow. The **Baseline condition** (see Figure 1.1) included a single neutral target face outlined in red. The target was presented in the cued hemifield with no distractor images presented. In the **Neutral Target condition**, two neutral faces were presented outlined in the target color red, but only one of which was presented in the cued hemifield (See Figure 1.2).

For the phonological filtering efficiency task, the same sequential presentation from the phonological simple change detection task was used. A visual depiction of the phonological version of the task in the current study can be found in Figure 3.

Participants were first cued to attend to either uppercase or lowercase words with a verbal instruction presented on screen at the beginning of each trial. Although the verbal cue was randomly chosen on each trial, the cue was counterbalanced across the experiment and equal proportions of uppercase and lowercase cues were used. Such counterbalancing was expected to reduce any systematic error that could arise from differences in the ease of recognition of uppercase versus lowercase words (e.g., see Vergara-Martínez et al., 2020). This instruction was presented for 500 milliseconds and indicated the to-be-remembered target stimuli for the trial. Next, participants were presented with the fixation cross for 300 milliseconds, following which the sequential study set was presented. Each item in the sequential study set was presented for 250

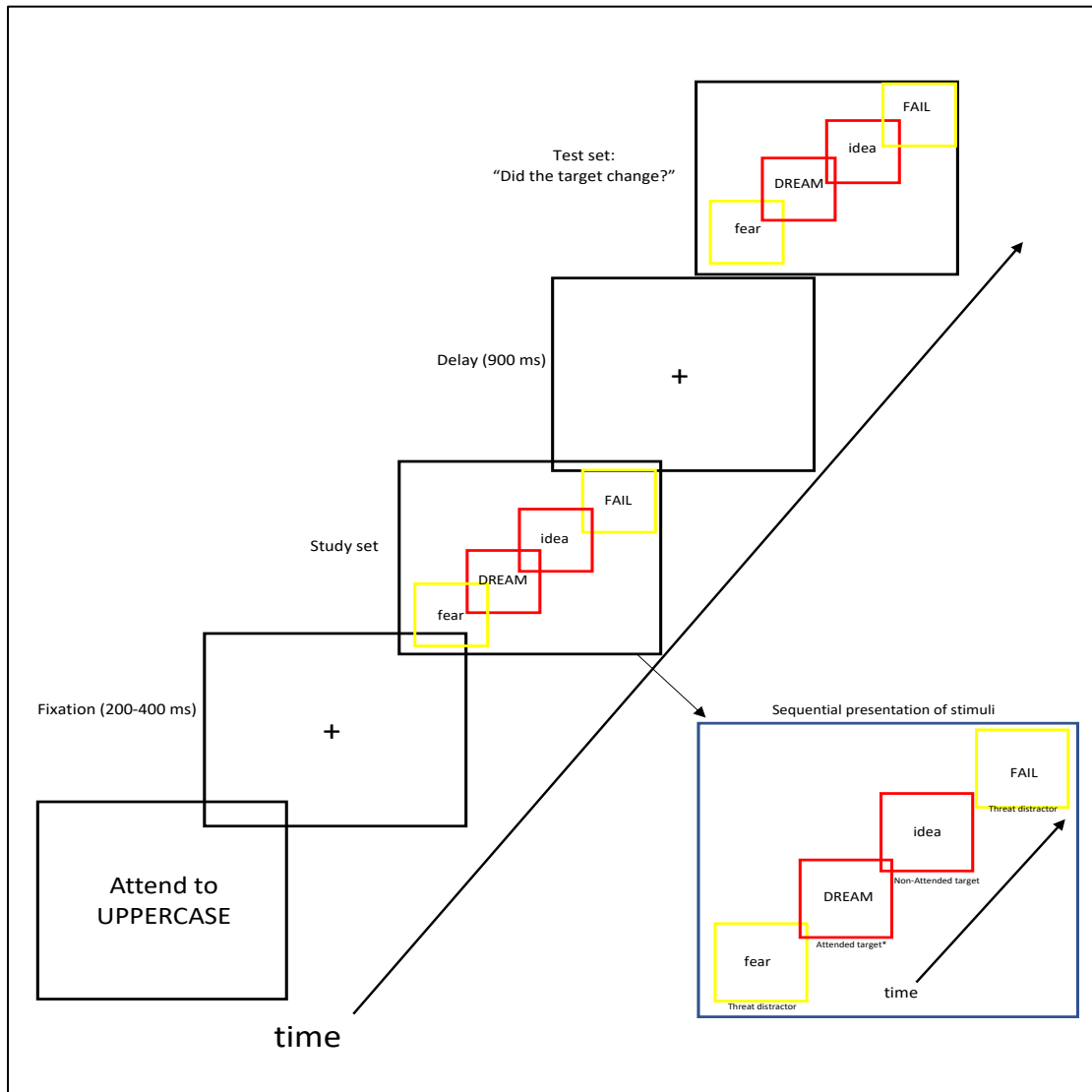


Figure 3. Visual depiction of trials for the phonological version of the change detection task⁷.

⁷ Note: Stimuli were presented sequentially for phonological stimuli. Targets were indicated by cued font type as well as the color outlining the image. In this example, the target is in uppercase and is outlined in red. Each target stimulus appeared in each of the 4 positions (i.e., 4 positions in serial order) twice—once as a change trial (i.e., the attended target changes in the test set), and once as a same trial (i.e., the attended target remains the same).

milliseconds (presentation time confirmed through pilot testing). Within each study set, stimuli were outlined in one of two colors (i.e., red or yellow), corresponding to target and distractor words. Participants were instructed to attend to and remember cued words (i.e., upper case or lower case) outlined in one color (i.e., target words) while ignoring words outlined in the other color.

For the phonological filtering efficiency task, the same target and distractor color assignment was used as for the visuospatial task. Target stimuli were always neutral words. Within cued stimuli (i.e., cued uppercase or lowercase words), one target word was presented alone or along with a distractor word. Thus, participants were cued to remember a single target word on each trial—that which was cued *and* outlined in the appropriate color. Following the presentation of the sequential study set, there was a 900-millisecond delay interval during which the fixation cross was presented alone and the target must be maintained in working memory. Finally, the test set was presented, and participants were asked to indicate via key press whether the target changed.

Notably, in the visuospatial filtering task, arrows were used to cue the participant to attend only to stimuli on one side of the display. For the phonological filtering task, uppercase and lowercase font were used in lieu of a spatial cue. The example shown in Figure 3 illustrates a case in which the target color is red and the distractor color is yellow. The participant (in this example) is instructed to attend to items in uppercase font and to ignore those in lowercase font. The **Baseline condition** included a single neutral target word outlined in target color red in upper case font with no distractor images presented. In the **Neutral Target condition**, two neutral words which were each indicated as targets (i.e., outlined in target color) are presented, one of which was

presented in the cued uppercase font, and the participant is instructed to remember the cued target stimulus only. In the **Neutral Distractor condition**, four neutral words were presented, two of which were presented in the uppercase cued font type. Two of the four words (i.e., one lowercase and one uppercase) were indicated as targets with the other two indicated as distractors (based on color outlining the stimulus). Participants were instructed to attend only to the cued stimuli, and to remember only the target word while ignoring distractors (See Figure 3 for example). Finally, the **Threat Distractor condition** has the same parameters as the Neutral Distractor condition, with the exception that distractor words (i.e., one upper case and one lower case) were threatening in nature (i.e., negative words; see Figure 3). In each condition, half of the trials were “same trials”, consisting of the same word presented in the same location in both study and test sets, while the other half were “change trials” (i.e., a new neutral word presented in the target location). On change trials for word stimuli, the word changed while the emotional valence remained the same (i.e., neutral).

The replacement stimulus on change trials (i.e., the face which appears in the target location in the test array or the word that appears in the target color and font type in the sequential set) was randomly selected from the set of neutral stimuli in the respective category (i.e., a randomly selected neutral word for word trials; a randomly selected model showing a neutral expression for face trials). In each of the four conditions, the 12 unique facial stimuli (i.e., models) and 12 unique word pairs (i.e., nouns), described above, were presented in each of the cued conditions (i.e., left or right hemifield; upper or lower case) four times, twice as the attended target (outlined in target color), and twice as the non-attended target. The remaining stimuli (i.e., non-

attended targets and distractor images) presented within trials of each condition were randomly selected from the appropriate set of unique neutral stimuli (i.e., faces or words). Each unique word and facial target stimulus was presented in each of four positions (i.e., each of the 4 quadrants for visuospatial stimuli and in each of the 4 positions in serial presentation for phonological stimuli; See Figure 1 and 3, respectively) twice throughout the experiment; once as a “same” trial and once as a “change” trial. This produced 8 trial types for each unique stimulus for each condition. This resulted in 96 trials for each of the two stimulus types in each of the four conditions, for a grand total of 768 trials. All facial stimuli trials and all word stimuli trials appeared together, each comprising half of the total experiment. The order of presentation of the blocks (i.e., words followed by faces; faces followed by words) was counterbalanced across participants.

Apparatus

Experimental stimuli were presented via E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA) on a Dell desktop running Windows 7, with a Dell P2414H monitor (i.e., 1920 x 1080 resolution and 60 Hz refresh). A standard QWERTY keyboard was used.

Face stimuli were cropped to an oval shape including only the face itself (i.e., removing hair, background, etc. from view). The size of each facial stimulus (i.e., including the surrounding box) was 5.5 cm in height and 4 cm in width. When presented within the bilateral display (i.e., simultaneous presentation), the oval face stimuli were surrounded by a 0.2 cm thick rectangular box which was 4.1 cm in width and 5.9 cm in height. Face stimuli were centered within the given quadrant, and there was a total of 1

cm distance from the bottom of the stimuli presented in the upper quadrants and the top of the stimuli presented in the lower quadrants. The distance between the center of each stimulus to the center of the (computer monitor) display was 4.3 cm. The arrow used to cue participants within this bilateral task was 0.9 cm in height and 2 cm in width, and was always centered within the display.

Word stimuli were presented in 24-point Consolas font (0.6 cm in height within the display) and were surrounded by a box which was 5.3 cm in width and 3.0 cm in height. All word stimuli were centered within the display within the sequential presentation. The cue for uppercase versus lowercase words was also centralized on the screen and presented in 24-point Consolas font.

Procedure

Participants completed the experiment in the Attention and Memory Lab at the University of New Brunswick (Fredericton). They provided informed consent to participate, following which they were directed to a computer to complete the study. The experimenter provided instructions for each component of the experiment and was present (in a neighbouring room) for the duration of the experimental session to answer questions as needed. Participants were first asked to complete the baseline working memory capacity task (i.e., visuospatial and phonological versions of the simple change detection task), the order of which was counterbalanced across participants. Following this, they were asked to complete both the visuospatial and phonological versions of the filtering change detection task (the order of which was also counterbalanced across participants). After completion, participants completed each of the Worry and Arousal

questionnaires (described under Measures) electronically⁸. Participants were then debriefed and compensated.

Data Analysis

Baseline working memory storage capacity (K). For each participant, baseline working memory storage capacity for each set size in the two simple change detection tasks (for each stimulus type: phonological and visuospatial stimuli) was estimated using Pashler's (1988) K formula: $S \times ([H-FA]/[1-FA])$, where S is the set size (i.e., the number of target faces; ranges from 1-4 for the simple change detection task; always equal to 1 for filtering change detection task), H is the hit rate (i.e., the proportion correct judgments on the change detection task), and FA is the false alarm rate (i.e., the proportion of "change" responses given when there was no change). K values were computed from responses on the simple change detection task and were used as the measure of baseline working memory storage capacity.

In addition to K values, participants' trial-by-trial accuracy for each set size in the two versions of the simple change detection task (i.e., phonological and visuospatial) were examined as an additional measure of baseline working memory performance without requiring data aggregation across trials. Results are thus presented for K value data as well as Accuracy data.

⁸ The original study design included a demographics questionnaire to self-report their age, gender, and previous anxiety disorder diagnoses (if relevant), so that such variables were available, if desired, for control purposes within analyses. However, this questionnaire was mistakenly omitted from the questionnaire package and thus this information was not collected. The participant pool from which the sample was drawn asks participants to report general demographic information (i.e., general age- under or over age 18, gender), but not all participants completed such screening, and due to appropriate privacy and confidentiality constraints, such information could not be linked to participant data from my study (i.e., which is coded via a confidential participant number). Given the lack of these demographics data, analyses using such details were not possible within the current work.

Filtering efficiency. The ability to prevent or inhibit distractor images from accessing working memory was calculated for each participant using a “filtering cost score”, where greater filtering costs (i.e., a larger value) indicates greater degradation of working memory for the target stimuli due to competition from distractor stimuli. Separate filtering cost scores were computed for neutral and threat distractors, and for the two stimulus types (i.e., phonological and visuospatial). Filtering cost for neutral distractors was calculated as the difference between working memory capacity (K , described above) for trials in the Neutral Target condition (i.e., with no distractors) and the Neutral Distractor condition (i.e., when a neutral target is paired with a neutral distractor), while filtering cost for threat distractors was calculated as the difference in K for trials in the Neutral Target condition and the Threat Distractor condition (i.e., when a neutral target is paired with a threat distractor).

In addition to examining filtering efficiency via K value calculations, participants’ trial-by-trial accuracy for each Distractor Type in the two versions of the filtering change detection task (i.e., phonological and visuospatial) were examined as an additional measure of working memory performance without requiring data aggregation across trials. Results are thus presented for K value data as well as Accuracy data.

Relationship between anxiety and filtering efficiency. The relationship between anxiety—both generally in terms of overall trait anxiety, and more specifically in terms of worry and anxious arousal, with filtering cost for threatening and neutral distractors was examined. To do so, R (R Core Team, 2020) and *lme4* was used to compare fit of linear mixed effects models with each of the anxiety variables (i.e., worry, arousal, and overall trait anxiety) and distractor type as fixed effects. Such comparisons were

conducted separately with filtering cost (computed via Pashler's K) or trial-by-trial accuracy as criterion variables. Comparisons were made separately for the phonological data and for the visuospatial data. The continuous predictors (i.e., worry, arousal, and overall trait anxiety) were mean centered. For each of the phonological and visuospatial stimulus datasets, three models were constructed in which one anxiety variable (i.e., *Worry*, *Arousal*, or *Trait Anxiety*) and *distractor type* (i.e., *DistractType*: threatening vs. neutral) were entered as fixed effects.

For trial-by-trial accuracy data, a base model was first constructed for each of the phonological and visuospatial stimulus types, to determine the best and most parsimonious random effects structure. This base model included the repeated measures variable (i.e., *DistractorType*) as the fixed effect. For random effects, the intercepts for subjects (i.e., 1|Subject) and stimuli (1|Stimuli) were tested using a restricted maximum likelihood approach (i.e., REML = TRUE). As well, by-subject random slopes were estimated for each distractor type (i.e., 1+*DistractorType*|Subject). Based on the recommendations of Bates and colleagues (2018), the more parsimonious model which best accounts for the data was selected as the base model from which to perform our model comparison. The base model was then used to create three anxiety models: a worry model (e.g., $\text{Accuracy} \sim \text{Worry} + \text{as.factor}(\text{DistractorType})$), an Arousal model (e.g., $\text{Accuracy} \sim \text{Arousal} + \text{as.factor}(\text{DistractorType})$); and an Overall Trait Anxiety model (e.g., $\text{Accuracy} \sim \text{Overall Trait Anxiety} + \text{as.factor}(\text{DistractorType})$). All models were first tested against a null model without the fixed factor of interest (i.e., worry, arousal, or trait anxiety). The difference in deviance between models was examined (i.e., the log-likelihood ratio), and the anova function was used to test the chi square

distribution to give a measure of model fit. If the models with the fixed anxiety variables provided a significantly better fit than the null model, comparisons across anxiety models were conducted. Specifically, three comparisons were conducted: anova (Worry Model, Arousal Model); anova (Overall Trait Anxiety Model, Worry Model); and anova (Overall Trait Anxiety Model, Arousal Model). This model comparison was conducted with both the visuospatial and phonological filtering cost datasets as outlined in the Research Questions and Contributions section above (see pp. 35-43). Maximum likelihood estimation was used for each comparison (i.e., REML=FALSE), as recommended by Faraway (2006) and Zurr and colleagues (2009) for comparison of models with the same random effect structure but with different fixed effects. A Holm correction was applied to all significant findings. Prior to conducting this analysis, assumptions of homoskedasticity and normality were examined through visual inspection of residual plots, and appropriate transformations were utilized in the case of assumption violations. Note that multicollinearity between Worry, Arousal, and Overall Trait Anxiety was not of concern as these variables were included in separate models only.

Baseline working memory storage capacity. R (R Core Team, 2020) and *lme4* was used to compare fit of linear mixed effects models with each of the anxiety variables (i.e., worry, arousal, and overall trait anxiety) as predictor variables. Such comparisons were conducted separately with Pashler's K (i.e., an estimate of WM storage capacity) and trial-by-trial accuracy on the baseline task as criterion variables. A base model was first constructed for each of the phonological and visuospatial stimulus types, to determine the best and most parsimonious random effects structure. For

Research Question 2, a base model was first constructed using the same approach outlined above for examining Research Question 1, and included the random intercept for subjects (i.e., 1|Subject) and random slope estimates across subjects for each set size (i.e., 1+SetSize|Subject) being tested using a restricted maximum likelihood approach (i.e., REML = TRUE). As there was no single target stimulus in the baseline working memory task (i.e., participants remembered between 2 and 5 words and between 1 and 4 images on a given trial), a random intercept for Stimulus was not included in these models. From the base model, three models were created for comparisons: a Worry model (i.e., Baseline WM storage capacity ~ Worry); an Arousal model (i.e., Baseline WM storage capacity ~ Arousal); and an Overall Trait Anxiety model (i.e., Baseline WM storage capacity ~ Overall Trait Anxiety). All models were first tested against a null model without the fixed factor of interest (i.e., worry, arousal, or trait anxiety). Model fit was compared across these three models using the same approach outlined above for examining Research Question 1, with the key difference that baseline working memory storage capacity was used as the criterion variable.

Relation of baseline working memory storage capacity to filtering efficiency.

As per Research Question 3, the relation of baseline working memory storage capacity (as measured by simple change detection task) to filtering efficiency in the complex change detection task was examined. Specifically, the current study examined whether baseline working memory capacity values (K) predicted filtering cost from the filtering change detection task. Interactions between anxiety and baseline working memory storage capacity and their effects on filtering efficiency were examined through a multiple regression with anxiety as a moderator. It was expected that baseline working

memory storage capacity would be a positive predictor of filtering efficiency and would be negatively associated with filtering cost. Furthermore, I examined whether anxiety (i.e., trait anxiety, worry, and/or arousal) moderated this relationship between baseline working memory storage capacity (K) and overall filtering efficiency (i.e., filtering cost) through the use of four multiple regression analyses. This analysis and corresponding research question were exploratory in nature and meant to further test the findings of a limited sample of previous research which suggested that anxiety interacts with working memory span to influence cognitive task performance (e.g., Stout & Rokke, 2010; Qi et al., 2014). Furthermore, the aim of this analysis was to delineate any relationships which may exist between these key variables that have not previously been examined due to previous studies in this area neglecting to consider a baseline measure of working memory storage capacity when examining the relationship between anxiety and filtering efficiency. In the first analysis, baseline working memory storage capacity (K) for phonological stimuli was entered as a predictor and worry was included as a moderator, with phonological filtering cost as the criterion variable. In the second analysis, baseline working memory storage capacity (K) for visuospatial stimuli was entered as a predictor and arousal was included as a moderator, with visuospatial filtering cost as the criterion variable. In the third analysis, baseline WM storage capacity (K) for phonological stimuli was entered as the predictor variable and Overall Trait Anxiety was included as a moderator to predict phonological filtering cost. Finally, in the fourth analysis, baseline WM storage capacity (K) for visuospatial stimuli was entered as the predictor variable, and Overall Trait anxiety was included as a moderator in predicting visuospatial filtering cost.

Processing efficiency. Finally, to examine processing efficiency of working memory as per Research Question 4, participants' patterns of response time (RT) across baseline and Neutral Target conditions of the change detection task was considered in three separate linear mixed effects analyses. Specifically, three models were created: a Worry model (e.g., Response Time ~ Worry + as.factor(DistractorType); an Arousal model (e.g., Response Time ~ Arousal + as.factor(DistractorType); and an Overall Trait Anxiety model (e.g., Response Time ~ Overall Trait Anxiety + as.factor(DistractorType). Distractor Type (i.e., baseline or Neutral Target condition) was included as a fixed effect in each model. Model fit was compared across these three models using the same approach outlined for Research Question 1 (i.e., the same model structures were used as for the filtering efficiency data), with response time as the criterion variable.

Notably, RTs were examined for accurate trials (i.e., those in which participants correctly detect whether there was a change or not). Following recommendations of Baayen and Milin (2010; also Baayen, 2008), minimal a priori data trimming was conducted, which included removing physically impossible short RTs (< 200 ms) and absurdly long latencies (> 5000 ms).

Results

Research Question 1: Filtering efficiency

Filtering Change Detection Task Accuracy

Average accuracy by Distractor Type for phonological and visuospatial versions of the complex (filtering) change detection task is reported in Table 4. As accuracy data

Table 4. Average accuracy by Distractor Type for phonological and visuospatial versions of the complex (filtering) change detection task

Task (stimulus type)	Distractor Type	Mean (SD)
Phonological	Baseline	0.96 (0.21)
	Neutral Target	0.91 (0.29)
	Neutral Distractor	0.87 (0.34)
	Threat Distractor	0.87 (0.33)
Visuospatial	Baseline	0.91 (0.29)
	Neutral Target	0.89 (0.31)
	Neutral Distractor	0.80 (0.40)
	Threat Distractor	0.78 (0.41)

Note: Standard deviations are reported in parentheses.

are binomial (i.e., scores of either 1 or 0 on each trial), the glmer function within the *lme4* package was used to examine this data, along with a glmer control “bobyqa” optimizer.

For both the phonological and visuospatial accuracy data, comparisons of random effects structures revealed a superior model fit for the full effects structure that included random intercepts for both Subject and Target Stimulus along with the random slope (e.g., $1 + \text{DistractorType} | \text{Subject}$ [Phonological $X^2(1) = 51.91, p < .001$; Visuospatial $X^2(1) = 42.34, p < .001$]). As such, this random effects structure (e.g., $[1 | \text{Subject}] + [1 | \text{TargetStimulus}] + [1 + \text{DistractorType} | \text{Subject}]$) was included in all further model comparisons. The base model was then used to create three anxiety models: A Worry model $[(\text{Accuracy} \sim \text{Worry} + \text{as.factor}(\text{DistractorType}))]$, an Arousal model $[(\text{Accuracy} \sim \text{Arousal} + \text{as.factor}(\text{DistractorType}))]$; and an overall Trait Anxiety model $[(\text{Accuracy} \sim \text{Trait Anxiety} + \text{as.factor}(\text{DistractorType}))]$. Each anxiety model was first tested against a null model without the fixed factor of interest (e.g., anxiety), using a maximum likelihood approach.

Phonological accuracy data. Results revealed that the worry model, arousal model, and trait anxiety model did not provide a superior fit to the data compared to the null model (Worry $X^2(1) = 0.11, p = .74$; Arousal $X^2(1) = 0.05, p = .82$; Trait Anxiety $X^2(1) = 0.03, p = .86$). Anxiety models were not compared to one another, as they were not significantly different from the null model. Examination of correlations revealed no significant correlations between accuracy and any of the anxiety variables (Worry $r = .006, p = .32$; Arousal $r = -.001, p = .83$; Trait Anxiety $r = .005, p = .49$).

Visuospatial accuracy data. Results revealed that neither the Worry model nor the Trait Anxiety model provided a superior fit to the data compared to the null model (Worry $\chi^2(1)=0.02$, $p=.88$; Trait Anxiety $\chi^2(1)=0.25$, $p=.62$). The Arousal model did provide a superior fit to the data compared to the null model, $\chi^2(1)=3.28$ $p=.07$. Comparisons of the Arousal model to the Worry and Trait Anxiety models using maximum likelihood estimation revealed lower deviance for the Arousal model (AIC= 18105, loglik = -9042.3) compared to both the Worry model (AIC= 18108, loglik= -9043.9) and the Trait Anxiety model (AIC=18108, loglik= -9043.8), with no difference between the Worry and Trait Anxiety models. Examination of correlations revealed a significant negative correlation between arousal and accuracy ($r= -.06$, $p<.001$), and a significant positive correlation between worry and accuracy ($r= .015$, $p<.05$). Further examination of the Arousal model with the Anova test function revealed a significant effect of DistractorType ($LR(3) = 551.96$, $p<.001$). Pairwise t-tests with a Holm correction showed that all differences among means were significant (largest $p = .01$), with the following order of means: Baseline > Neutral Target > Neutral Distractor > Threat Distractor. Results also showed a trend toward decreasing accuracy with increasing arousal; however, this effect was not statistically significant ($p=.07$).

Filtering cost (computed via Pashler's K)

Average filtering cost by Distractor Type for phonological and visuospatial versions of the complex change detection task is reported in Table 5. Model comparisons were conducted separately for phonological and visuospatial data, as presented below. For the random effects structure, a random intercept for Subject was included in all models. While a random intercept for Stimuli was considered, it was not

Table 5. Average filtering cost by Distractor Type for phonological and visuospatial versions of the complex (filtering) change detection task.

Task (stimulus type)	Distractor Type	Mean (SD)
Phonological	Threat	0.04 (0.06)
	Neutral	0.05 (0.07)
Visuospatial	Threat	0.16 (0.16)
	Neutral	0.13 (0.14)

Note: Standard deviations are reported in parentheses.

possible to include it in this analysis as Filtering Cost is computed via the Pashler's K formula, which requires aggregation of data across stimuli/trials. The base model was then used to create three anxiety models: A Worry model [(FilteringCost~Worry + as.factor(StimulusType)], an Arousal model [(FilteringCost~Arousal + as.factor(Stimulus Type)]; and an overall Trait Anxiety model [(FilteringCost~Worry + as.factor(Stimulus Type)], where Stimulus Type represented filtering cost for threatening distractors or neutral distractors. Each anxiety model was first tested against a null model without the fixed factor of interest (e.g., anxiety), using a maximum likelihood approach (e.g., REML=FALSE).

Phonological filtering cost data. Assumptions testing revealed violations of the linearity assumption for each of the three models. As such, the data were log-transformed prior to model comparisons. To account for negative and zero values within Filtering Cost, a constant ($a=0.07$) was first added to each filtering cost value prior to the log transformation, to ensure all values were positive. Results revealed that the Worry model, Arousal model, and Trait Anxiety models did not provide a superior fit to the data compared to the null model (Worry [$\chi^2(1)=2.49, p=.11$]; Arousal [$\chi^2(1)=0.51, p=.48$]; Trait Anxiety [$\chi^2(1)=2.15, p=.14$]). Examination of correlations revealed a significant negative correlation between worry and filtering cost ($r=-.23, p<.02$), and a significant negative correlation between trait anxiety and filtering cost ($r=-.21, p<.03$). There was no significant correlation between arousal and filtering cost ($r=-.09, p=.33$). Results of a paired t-test revealed no significant differences in filtering cost between threat ($M=0.04, SD=0.06$) and neutral ($M=0.05, SD=0.07$) distractors, $t(116.86)=0.99, p=.32$.

Visuospatial filtering cost data. Assumptions testing revealed violations of the linearity assumption for each of the three models, as well as heteroskedasticity of Arousal (Levene's $p < .05$). As such, the data were log-transformed prior to model comparisons. Results revealed that the Worry model, Arousal model, and Trait Anxiety model did not provide a superior fit to the data compared to the null model (Worry $X^2(1)=1.03, p=.31$; Arousal $X^2(1)=0.81, p=.37$; Trait Anxiety $X^2(1)=0.23, p=.63$). Anxiety models were not compared to one another, as they were not significantly different from the null model. Examination of correlations revealed no significant correlations between filtering cost and any of the anxiety variables (Worry $r = -.12, p=.19$; Arousal $r = .11, p=.24$; Trait Anxiety $r = -.06, p=.54$). Results of a paired t -test revealed no significant differences in filtering cost between threat ($M=0.13, SD=0.14$) and neutral ($M=0.16, SD=0.16$) distractors, $t(117.33) = -1.28, p=.20$.

Research Question 2: Baseline Working Memory Storage Capacity

Baseline Task Accuracy

Average accuracy by Set Size for visuospatial and phonological data from the simple change detection task is reported in Table 6. As with accuracy data for Research Question 1, the glmer function within the *lme4* was used to examine this binomial data, along with a glmer control “bobyqa” optimizer, and trials with response times less than 200 milliseconds or longer than 5000 milliseconds were removed prior to all analyses. For both the phonological and visuospatial accuracy data, three anxiety models were created: A Worry model [(Accuracy~Worry + as.factor(SetSize))], an Arousal model [(Accuracy~Arousal + as.factor(SetSize))]; and an overall Trait Anxiety model [(Accuracy~ Trait Anxiety + as.factor(SetSize))]. For each model, a random intercept for

Table 6. Average accuracy by Set Size for phonological and visuospatial versions of the baseline change detection task

Task (stimulus type)	Set Size	Mean (SD)
Phonological	Set Size 2	0.95 (0.23)
	Set Size 3	0.91 (0.29)
	Set Size 4	0.84 (0.36)
	Set Size 5	0.76 (0.43)
Visuospatial	Set Size 1	0.87 (0.33)
	Set Size 2	0.67 (0.47)
	Set Size 3	0.61 (0.49)
	Set Size 4	0.57 (0.50)

Subject (e.g., 1|Subject) and random slope estimates across subjects for each SetSize (e.g., 1+SetSize|Subject) were included following examination of the best fitting and most parsimonious random effects structure (as recommended by Bates et al., 2018). Unlike analyses for Research Question 1, which included random intercepts for Stimulus in addition to that for Subject, a random intercept for Stimulus was not appropriate in the current analyses as there was no single target stimulus in the baseline working memory task (e.g., participants remembered between up to 4 images and up to 5 words on a given trial). Each anxiety model was first tested against a null model without the fixed factor of interest (e.g., anxiety), using a maximum likelihood approach.

Phonological accuracy data. Assumptions testing revealed no concerns with heteroskedasticity (Levene's p 's $> .11$). Results revealed that the worry model, arousal model, and trait anxiety model did not provide a superior fit to the data compared to the null model (Worry $X^2(1)=0.55$, $p=.46$; Arousal $X^2(1)=0.99$, $p=.32$; Trait Anxiety $X^2(1)=0.84$, $p=.36$). Anxiety models were not compared to one another, as they were not significantly different from the null model. Examination of correlations revealed no significant correlations between overall accuracy and any of the anxiety variables (Worry $r= -.02$, $p=.11$; Arousal $r= -.0002$, $p=.99$; Trait Anxiety $r= -.01$, $p= .21$), nor between the anxiety variables and accuracy across set sizes (p 's $> .09$). Results of a one-way ANOVA revealed a significant main effect of Set Size on Accuracy, $F(1) = 393.5$, $p< .001$. Pairwise t -tests with a Holm correction showed that all differences among means were significant (largest $p = .0004$), with decreasing accuracy with increasing set size (i.e., Set Size 2 > Set Size 3 > Set Size 4 > Set Size 5).

Visuospatial accuracy data. Assumptions testing revealed no concerns with heteroskedasticity (Levene's p 's $> .61$). Results revealed that the worry model, arousal model, and trait anxiety model did not provide a superior fit to the data compared to the null model (Worry $X^2(1) = 0.73, p = .39$; Arousal $X^2(1) = 0.06, p = .81$; Trait Anxiety $X^2(1) = 0.33, p = .56$). Anxiety models were not compared to one another, as they were not significantly different from the null model. Examination of correlations revealed no significant correlations between overall accuracy and any of the anxiety variables (Worry $r = .01, p = .34$; Arousal $r = -.006, p = .856$; Trait Anxiety $r = .006, p = .60$). Although examination of correlations between the anxiety variables and accuracy across set sizes were suggestive of a negative correlation between arousal and accuracy for a set size of 1, this correlation was not significant, ($r = -.03, p = .06$). No other correlations were significant across anxiety variables and set sizes. Results of a one-way ANOVA revealed a significant main effect of Set Size on Accuracy, $F(1) = 495.1, p < .001$. Pairwise t -tests with a Holm correction showed that all differences among means were significant (largest $p = .006$), with decreasing accuracy with increasing set size (i.e., Set Size 1 > Set Size 2 > Set Size 3 > Set Size 4).

Working Memory Storage Capacity (Pashler's K)

Average working memory storage capacity (i.e., Pashler's K) values by set size for phonological and visuospatial versions of the baseline change detection task are reported in Table 7.

Phonological working memory storage capacity data. Assumptions testing revealed no concerns regarding heteroskedasticity (Levene's p 's $> .25$), but violations of the linearity and normality of residuals assumptions (as per visual inspection of residual

Table 7. Average working memory capacity (Pashler's K) by Set Size for phonological and visuospatial versions of the baseline change detection task

Task (stimulus type)	Set Size	Mean (SD)
Phonological	Set Size 2	1.90 (0.18)
	Set Size 3	2.68 (0.40)
	Set Size 4	3.11 (0.85)
	Set Size 5	3.29 (1.07)
Visuospatial	Set Size 1	0.85 (0.16)
	Set Size 2	0.90 (0.39)
	Set Size 3	0.86 (0.52)
	Set Size 4	0.68 (0.86)

Note: Standard deviations are reported in parentheses.

and QQ plots). A log transformation was thus performed on the Pashler's K values prior to model comparisons.

Results revealed that the worry model, arousal model, and trait anxiety model did not provide a superior fit to the data compared to the null model (Worry $X^2(1) = 0.48, p = .49$; Arousal $X^2(1) = 0.01, p = .93$; Trait Anxiety $X^2(1) = 0.25, p = .61$). Anxiety models were not compared to one another, as they were not significantly different from the null model. Examination of correlations revealed no significant correlations between baseline working memory storage capacity (i.e., Pashler's K) and any of the anxiety variables across set sizes (p 's $> .08$). Results of a one-way ANOVA revealed a significant main effect of Set Size on Pashler's K values, $F(1) = 119.7, p < .001$. Pairwise t -tests with a Holm correction showed increasing Pashler's K values for Set Sizes 2, 3 and 4 (i.e., Set Size 2 $<$ Set Size 3 $<$ Set Size 4; largest $p = .002$), but no significant differences between Set size 4 and Set Size 5 ($p = .16$).

Visuospatial working memory storage capacity data. Assumptions testing revealed no issues with heteroskedasticity (Levene's p 's $> .61$), but the assumption of normality of residuals was violated for each of the three anxiety models (as per visual inspection of QQ plots). As such, a log transformation was performed on the Pashler's K values prior to model comparisons. To account for negative and zero values within Pashler's K values, a constant ($a=2.5$) was first added to each Pashler's K value prior to the log transformation, to ensure all values were positive. Results revealed that the worry model, arousal model, and trait anxiety model did not provide a superior fit to the data compared to the null model (Worry $X^2(1) = 0.03, p = .85$; Arousal $X^2(1) = 0.67, p = .41$; Trait Anxiety $X^2(1) = 0.02, p = .89$). Anxiety models were not compared to one

another, as they were not significantly different from the null model. Examination of correlations revealed no significant correlations between overall baseline working memory storage capacity (as indexed by Pashler's K) and any of the anxiety variables (Worry $r = .04, p = .53$; Arousal $r = -.03, p = .59$; Trait Anxiety $r = .02, p = .76$), nor between anxiety variables and Pashler's K values across set sizes (p 's $> .16$). Results of a one-way ANOVA revealed no significant main effect of Set Size on Pashler's K values, $F(1) = 2.98, p = .08$.

Research Question 3: Relationship between WM storage capacity and Filtering Cost

Phonological data

Shapiro-Wilk's test of normality revealed violations in the normality assumption for both Neutral Filtering Cost scores ($W = .89, p < .001$) and Threat Filtering Cost scores ($W = .78, p < .001$). As such, a log transformation was performed on Filtering Cost for Neutral distractors and Filtering Cost for Threat distractors. The *lm* function in R was used to examine potential interactions between worry (or trait anxiety) and baseline working memory storage capacity (from the simple change detection task) in predicting filtering cost for neutral and threat distractors (from the complex filtering task). Interactions were examined for each set size (2, 3, 4, and 5).

Worry. Results revealed no significant interactions between worry and baseline working memory storage capacity (Pashler's K) in predicting Filtering cost for Neutral distractors, regardless of set size (Set size 2, $t = 0.07, p = .94$; Set size 3, $t = -0.67, p = .51$; Set size 4, $t = -0.74, p = .46$; Set Size 5, $t = -1.04, p = .30$). However, baseline working memory storage capacity (Pashler's K) was a significant negative predictor of filtering

cost for neutral distractors across set sizes (Set size 2, $t = -1.99$, $p = .05$; Set size 3, $t = -2.62$, $p < .02$; Set size 4, $t = -2.92$, $p < .01$; Set Size 5, $t = -2.42$, $p < .02$). For Threat distractors, results revealed no significant interactions between worry and baseline working memory storage capacity in predicting filtering cost, across set sizes (Set size 2, $t = 0.17$, $p = .87$; Set size 3, $t = -1.30$, $p = .20$; Set size 4, $t = -0.39$, $p = .70$; Set Size 5, $t = 0.49$, $p = .63$). Working memory storage capacity (Pashler's K) was not a significant predictor of filtering cost for threat distractors (Set size 2, $t = 0.33$, $p = .75$; Set size 3, $t = 0.92$, $p = .36$; Set size 4, $t = 0.06$, $p = .95$; Set Size 5, $t = -0.58$, $p = .57$).

Trait Anxiety. Results revealed no significant interactions between trait anxiety and baseline WM storage capacity in predicting filtering cost for either neutral distractors (Set size 2, $t = 0.10$, $p = .92$; Set size 3, $t = -0.50$, $p = .62$; Set size 4, $t = -0.61$, $p = .54$; Set Size 5, $t = -1.20$, $p = .23$) or threat distractors (Set size 2, $t = 0.08$, $p = .94$; Set size 3, $t = -1.17$, $p = .25$; Set size 4, $t = -0.39$, $p = .70$; Set Size 5, $t = 0.62$, $p = .54$). Working memory storage capacity (Pashler's K) was a significant predictor of filtering cost for neutral distractors across all set sizes (Set size 2, $t = -1.97$, $p = .05$; Set size 3, $t = -2.60$, $p = .02$; Set size 4, $t = -2.92$, $p < .01$; Set Size 5, $t = -2.47$, $p < .02$), but not for threat distractors (Set size 2, $t = 0.30$, $p = .76$; Set size 3, $t = 0.84$, $p = .41$; Set size 4, $t = 0.04$, $p = .97$; Set Size 5, $t = -0.53$, $p = .60$).

Visuospatial data

Shapiro-Wilk's test of normality revealed violations in the normality assumption for both Neutral Filtering Cost scores ($W = .78$, $p < .001$) and Threat Filtering Cost scores ($W = .82$, $p < .001$). As such, a log transformation was performed on Filtering Cost for Neutral distractors and Filtering Cost for Threat distractors. The *lm* function in R was

used to examine potential interactions between arousal (or trait anxiety) and baseline working memory storage capacity (from the simple change detection task) in predicting filtering cost for neutral and threat distractors (from the complex filtering task).

Interactions were examined for each set size (1-4).

Arousal. Results revealed no significant interactions between arousal and baseline WM storage capacity (i.e., across set sizes 1-4) in predicting filtering cost for either threat distractors (Set Size 1, $t = -0.21$, $p = .83$; Set Size 2, $t = 0.99$, $p = .33$; Set Size 3, $t = 1.03$, $p = .31$; Set Size 4, $t = -0.36$, $p = .72$) or neutral distractors (Set Size 1, $t = -1.80$, $p = .08$; Set Size 2, $t = 0.22$, $p = .83$; Set Size 3, $t = 1.02$, $p = .31$; Set Size 4, $t = 0.32$, $p = .75$). Working memory storage capacity was not a significant predictor of filtering cost for neutral distractors across set sizes (Set size 1, $t = -0.97$, $p = 0.34$; Set size 2, $t = -0.80$, $p = .43$; Set size 3, $t = -0.45$, $p = .65$; Set size 4, $t = 0.48$, $p = .63$), or for threat distractors across set sizes (Set size 1, $t = -0.24$, $p = .81$; Set size 2, $t = 0.87$, $p = .39$; Set size 3, $t = -0.24$, $p = .81$; Set Size 4, $t = -0.62$, $p = .54$).

Trait Anxiety. Results revealed no significant interactions between trait anxiety and baseline WM storage capacity (i.e., across set sizes 1, 2, 3 and 4) in predicting filtering cost for either threat distractors (Set size 1, $t = 0.75$, $p = .45$; Set size 2, $t = 1.23$, $p = .21$; Set size 3, $t = 1.02$, $p = .31$; Set Size 4, $t = -0.20$, $p = .84$) or neutral distractors (Set size 1, $t = -1.14$, $p = .26$; Set size 2, $t = 0.50$, $p = .62$; Set size 3, $t = -0.01$, $p = .99$; Set Size 4, $t = -0.30$, $p = .77$). Furthermore, across set sizes, working memory storage capacity was not a significant predictor of filtering cost for neutral distractors (Set size 1, $t = -1.10$, $p = .28$; Set size 2, $t = -0.82$, $p = .41$; Set size 3, $t = -0.34$, $p = .73$; Set Size 4, $t = 0.58$, $p = .56$) or

threat distractors (Set size 1, $t = -0.41$, $p = .68$; Set size 2, $t = 1.04$, $p = .30$; Set size 3, $t = -0.07$, $p = .94$; Set Size 4, $t = -0.60$, $p = .55$).

Research Question 4: Processing Efficiency (Response Time)

Participants' response times on Baseline and Neutral Target conditions of the complex change detection task were examined. The following steps were conducted separately for both the phonological and visuospatial data. Data were first filtered to include only accurate trials (i.e., those in which participants correctly detected whether there was a change or not).

To determine an appropriate base model with the best and most parsimonious random effects structure, a model with random intercepts for Subject and Target Stimulus [(ResponseTime ~ as.factor(DistractorType) + (1|TargetImage) + (1|Subject))] was compared to a model with only a random intercept for Subject [(ResponseTime ~ as.factor(DistractorType) + (1|Subject))], a model with only a random intercept for Target Stimulus [(ResponseTime ~ as.factor(DistractorType) + (1|TargetImage))], as well as a model with both random intercepts for Subject and Target Stimulus as well as a random slope (i.e., 1+DistractorType|Subject). Models were compared using a restricted maximum likelihood approach (REML=TRUE). Results revealed a superior model fit for the full random effects structure with both random intercepts (i.e., 1|Subject and 1|TargetImage) as well as the random slope (i.e., 1+DistractorType|Subject) for phonological data ($X^2(1) = 20.66$, $p < .001$). For visuospatial data, inclusion of the random slope (i.e., 1+DistractorType|Subject) did not improve model fit over the random intercepts for Subject and Target Stimuli ($X^2(1) = 1783.90$, $p < .001$), and thus was not included in model comparisons for visuospatial data. Base models were then

used to create three anxiety models: A Worry model [(ResponseTime~Worry + as.factor(DistractorType)], an Arousal model [(ResponseTime~Arousal + as.factor(DistractorType)]; and an overall Trait Anxiety model [(ResponseTime~ Trait Anxiety + as.factor(DistractorType)]. Each anxiety model was first tested against a null model without the fixed factor of interest (i.e., anxiety), using a maximum likelihood approach.

Phonological data

Assumptions testing revealed no concerns with heteroskedasticity (Levene's $p > .17$) but violations of the assumptions of linearity and normality of residuals for each of the three models (as per visual inspection of residual plots and QQ plots). An inverse log transformation was conducted on the response time data prior to model comparisons. Results revealed that the worry model, arousal model, and trait anxiety model did not provide a superior fit to the data compared to the null model (Worry $X^2(1)=0.01, p=.94$; Arousal $X^2(1) = 0.06, p=.80$; Trait Anxiety $X^2(1) = 0.02, p=.89$). Anxiety models were not compared to one another, as they were not significantly different from the null model. Examination of correlations revealed a significant positive correlation between response time and Arousal ($r=.02, p<.05$), but no significant correlation between worry and response time ($r=-.01, p=.34$), nor between trait anxiety and response time ($r=-.0005, p=.96$).

Visuospatial data

Assumptions testing revealed heteroskedasticity for Arousal (Levene's $p<.01$) and Trait Anxiety (Levene's $p<.05$), but homoskedasticity for Worry (Levene's $p=.56$), as well as violations of the assumptions of linearity and normality of residuals for each

of the three models (as per visual inspection of residual plots and QQ plots). An inverse log transformation was thus conducted on the response time data prior to model comparisons.

Results revealed that the worry model, arousal model, and trait anxiety model did not provide a superior fit to the data compared to the null model (Worry $X^2(1)=0.03$, $p=.85$; Arousal $X^2(1) = 0.02$, $p=.88$; Trait Anxiety $X^2(1) = 0.01$, $p=.93$). Anxiety models were not compared to one another, as they were not significantly different from the null model. Examination of correlations revealed a significant positive correlation between response time and Arousal ($r=.031$, $p<.001$), but no significant correlation between worry and response time ($r=-.01$, $p=.35$), nor between trait anxiety and response time ($r=.002$, $p=.82$).

Discussion

The current dissertation examined the relationship between anxiety and working memory. The primary goal was to resolve noted limitations and inconsistencies of past research (such as those identified by Moran, 2016), as well as to extend this work. This involved examination of trait (as opposed to state) anxiety, and underlying components of arousal and worry, along with consideration of *both* phonological and visuospatial working memory. Working memory was primarily operationalized via filtering efficiency, or the ability to inhibit irrelevant or distracting information from accessing working memory during a cognitive task. Prominent models of the working memory and anxiety relationship subdivide working memory into visuospatial and phonological components. However, the literature examining filtering efficiency has focused on

visuospatial working memory (e.g., using working memory tasks with facial stimuli) to the neglect of phonological.

My dissertation contributes to the literature by presenting a novel task which appears to examine phonological working memory while being parallel to the visuospatial working memory tasks utilized in previous research (e.g., Stout et al., 2013; 2015). Development of such a task appears valuable to allow for examination of domain-specific interactions between anxiety and filtering efficiency. While the validity of such task to examine phonological working memory should be considered in additional experiments, results from the current study (and pilot study) appear promising. Participants' processing efficiency, or the efficiency with which individuals process information in working memory to make accurate responses on working memory tasks, as well as participants' baseline working memory storage capacity were also examined for both phonological and visuospatial stimuli. Finally, the role of threat in the anxiety and working memory relationship was also considered. Results from the current study provide key advancements toward elucidating the underlying mechanisms of the trait anxiety and working memory relationship and suggest a role for *both* domain-general and domain-specific interference. A summary of results for each research question and corresponding analyses is presented in Table 8. In-depth discussion of results follows below.

Research Question 1

Research Question 1 sought to determine if the relationship between anxiety and reduced filtering efficiency is better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT), the

Table 8. Summary of key results for each research question.

Research Question	Phonological Results	Visuospatial Results
<i>RQ1</i> : Is the relationship between anxiety and reduced filtering efficiency better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT) or the domain-specific interference account of the Two Component Model? Or, are the two accounts complementary to one another?	Phonological accuracy data: - Worry, Arousal, and Trait Anxiety models not significantly different from null model (without anxiety variables). - No support for explanatory models. Phonological Filtering Cost (Pashler's K) data: - Worry, Arousal, and Trait Anxiety models not significantly different from null model. - Significant negative correlation between Worry and Filtering cost (as worry increased, filtering cost decreased). *	Visuospatial accuracy data: - Arousal > Trait Anxiety and Worry models. - Higher arousal associated with reduced visuospatial task accuracy. - Supports domain-specific interference (Two Component Model and Moran's model). - Significant positive correlation between Worry and Accuracy. * Visuospatial Filtering Cost (Pashler's K) data: - Worry, Arousal, and Trait Anxiety models not significantly different from null model. - No support for explanatory models.
<i>RQ2</i> : Is the relationship between anxiety and baseline working memory storage capacity better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT) or the domain-specific interference account of the Two Component Model? Or,	Phonological accuracy data: - Worry, Arousal, and Trait Anxiety models not significantly different from null model. - No support for explanatory models. Phonological working memory storage capacity data: - Worry, Arousal, and Trait Anxiety models not significantly different from null model.	Visuospatial accuracy data: - Worry, Arousal, and Trait Anxiety models not significantly different from null model. - No support for explanatory models. Visuospatial working memory storage capacity data: - Worry, Arousal, and Trait Anxiety models not significantly different from null model.

are the two accounts complementary to one another?	- No support for explanatory models.	- No support for explanatory models.
RQ3: Does anxiety (e.g., worry, arousal, and/or trait anxiety) moderate the relationship between baseline working memory storage capacity and filtering efficiency, and does this moderation depend on the type of stimuli included in the working memory tasks (e.g., phonological or visuospatial)?	- No significant interactions between baseline working memory storage capacity and anxiety (e.g., worry or trait anxiety) in predicting filtering cost. - Baseline working memory storage capacity (Pashler's K) was a significant negative predictor of filtering cost for <u>neutral distractors</u> but <u>not threat distractors</u> across set sizes.	- No significant interactions between baseline working memory storage capacity and anxiety (e.g., arousal or trait anxiety) in predicting filtering cost. - Baseline working memory storage capacity (Pashler's K) was <u>not</u> significant negative predictor of filtering cost for neutral or threat distractors, regardless of set size.
RQ4: Is the relationship between anxiety and longer response times (e.g., reduced processing efficiency) better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT) or the domain-specific interference account of the Two Component Model? Or, are the two accounts complementary to one another?	- Worry, Arousal, and Trait Anxiety models not significantly different from null model. - Significant positive correlation between Arousal and Response Time. **	- Worry, Arousal, and Trait Anxiety models not significantly different from null model. - Significant positive correlation between Arousal and Response Time. **

*Taken together, findings support a domain-general relationship between worry and working memory, with worry associated with *improved* task performance across stimulus types.

**Taken together, findings support a domain-general relationship between arousal and processing efficiency, with arousal associated with *decreased* processing efficiency across stimulus type

domain-specific interference account of the Two Component Model, or whether the two accounts are complementary to one another, as proposed by Moran (2016).

Results from the complex change detection task with visuospatial stimuli (e.g., faces) revealed that self-reported trait arousal better predicted working memory filtering efficiency compared to self-reported trait worry and overall trait anxiety. Additionally, examination of correlations revealed higher levels of arousal were associated with reduced accuracy on the visuospatial change detection task. These results support the Two Component Model, which argues that the interference of anxiety with working memory is *domain-specific* such that different components of anxiety (e.g., worry and arousal) differentially disrupt working memory depending upon the type of stimuli involved (e.g., phonological and visuospatial, respectively; Vytal et al., 2012; 2013). While evidence for this theory has primarily relied on examining anxious arousal in the context of *state* anxiety (e.g., situational) through use of the threat-of-shock paradigm (Vytal et al., 2012; 2013), my dissertation results extend these findings to *trait* arousal. That is, individuals with greater tendency to experience symptoms of arousal regularly and across situations (e.g., shortness of breath, dizziness, shaky hands, dry mouth) were more likely to show impaired accuracy on the visuospatial change detection task compared to those with lower trait arousal.

The current results are consistent with the Two Component Model's prediction for the relationship between arousal and visuospatial working memory, with increased anxious arousal consistently disrupting visuospatial working memory due to shared neural resources and a limited ability to engage in top-down attentional control over

such neural resources (Robinson et al., 2013a; 2013b; Vytal et al., 2012; 2013). It is argued that anxious arousal and visuospatial working memory involve activation of the same brain regions—the right prefrontal cortex and right posterior parietal cortex—and thus compete for neural resources. Anxious arousal is said to have an evolutionary survival advantage and involves an automatic preparatory response which primes defensive mechanisms, and thus takes priority over access to neural resources. This results in fewer resources available for visuospatial working memory and thus reduced task performance under heightened arousal (Robinson et al., 2013a; 2013b; Vytal et al., 2012; 2013).

Unexpectedly, results also indicated that worry was positively correlated with accuracy on the visuospatial change detection task. This pattern is not predicted by the Two Component Model for two reasons. First, according to this model, anxiety is generally expected to be associated with impaired working memory task performance, rather than improved working memory performance. Further, worry is predicted to be related to phonological working memory and unrelated to visuospatial working memory (Vytal et al., 2012; 2013). Instead, this result can be explained by appeal to Processing Efficiency Theory, as early proponents argued that individuals with high anxiety, including high levels of worry, are motivated to avoid aversive consequences (Eysenck & Calvo, 1992). Individuals with high anxiety are thus said to devote *increased* effort to cognitive task performance to avoid such consequences (Eysenck & Calvo, 1992).

Worry is assumed to be related to domain-general central executive performance, which involves a control system that is sensitive to failure feedback about performance (e.g., that performance is falling below what is required or expected; Eysenck & Calvo, 1992;

Eysenck et al., 2005). When such feedback is encountered, worry about task performance may encourage the central executive to allocate attention and effort to the task, and to initiate strategies to improve performance and avoid poor performance or negative evaluation (Eysenck & Calvo, 1992; Eysenck et al., 2005). PET ultimately argues that worry is associated with an increase in on-task effort and activities designed to improve performance. Thus, it may be that worry was adaptive in the current study in terms of improving task accuracy by way of increased effort and attention to the task.

When considering filtering cost (computed via Pashler's K values) for neutral and threatening distractors on the visuospatial filtering task, the anxiety variables were unrelated to performance. These results contrasted with previous results, which highlighted a relationship between anxiety and impaired inhibition or filtering efficiency. Moran (2016) conducted a meta-analysis and found that anxiety robustly predicted poorer gating of irrelevant information (e.g., threatening and neutral distractors) from working memory, and highlighted interference with the domain-general system of working memory. Results from the filtering task with faces in the current study found a relationship between arousal and overall accuracy, but do not support previous findings specific to filtering cost. That is, worry, arousal, and overall trait anxiety were unrelated to visuospatial filtering cost for threatening or neutral distractors in the current study. As well, results showed no significant difference in filtering cost for threatening versus neutral distractors, suggesting that potentially threatening information was not more distracting or more difficult to ignore than neutral information in the current study.

Results from the complex change detection task with phonological stimuli (i.e., words) were more unexpected. The outcome of the linear mixed effects model comparison suggested that neither worry nor overall trait anxiety were influential in predicting performance on the complex change detection task with words. As such, results do not directly support the Two Component Model, Processing Efficiency Theory/Attentional Control Theory, or Moran's (2016) model. The current results are consistent with The Two Component Model's predictions regarding arousal; namely, the arousal model did not provide a better predictive fit of this data as compared to a null model without this variable, suggesting that phonological working memory task performance was unrelated to anxious arousal, as predicted by the Two Component Model (Robinson et al., 2013a; 2013b; Shackman et al., 2006). Contrary to predictions of the Two Component Model, however, worry was not associated with impaired performance on this phonological task. In fact, when considering filtering cost computed via Pashler's K values, worry was again associated with *improved* performance (i.e., reduced filtering cost). Such results held true for both threat and neutral distractors, suggesting that individuals with higher levels of worry were *less* disrupted by distracting information regardless of the nature of such distractors. Such findings conflict with Stout and colleagues' (2015) conclusions that worry is associated with inefficient filtering of threat-related (but not neutral) distractors from working memory as it is uniquely associated with failure to inhibit task-irrelevant threat from working memory. Additionally, Stout and colleagues (2015) found that overall trait anxiety was related to inefficient filtering of both threat and neutral distractor stimuli. This also was not replicated in the current study, as overall trait anxiety was unrelated to filtering

efficiency. Similar to what was observed for visuospatial filtering efficiency, there was no significant difference between filtering cost for threatening versus neutral distractors within the phonological task overall (i.e., irrespective of anxiety level). This suggests that filtering or ignoring distracting information is equally challenging regardless of the nature (i.e., neutral or potentially threatening) of the distracting information.

The unexpected findings related to worry and phonological task performance in the current study may be explained by early work supporting Processing Efficiency Theory, which argued for increased effort and attention being allocated to cognitive tasks among individuals with higher levels of worry, in attempt to avoid aversive consequences such as poor task performance (Eysenck & Calvo, 1992; Eysenck et al., 2005). Notably, such findings have been supported by other work examining state levels of worry (e.g., Sari, Koster & Derakshan, 2017) as well as trait levels (Held, Vîslă, Zinbarg, Wolfer, & Flückiger, 2020).

Moreover, studies supporting the Two Component Model have highlighted differential effects of worry on verbal working memory depending on the level of task difficulty (Vytal et al., 2012). Impaired performance is said to be most likely to occur on tasks of low difficulty; in contrast, under high task difficulty (e.g., when cognitive load and attentional demands are high), task performance takes precedence over worry, and performance is improved (Vytal et al., 2012). The phonological change detection task in the current study was not expected to be of high difficulty, particularly given results from pilot testing of this task which revealed over 85% accuracy across set sizes (refer to Appendix C for additional details). However, this phonological task may have been more cognitively demanding than anticipated and may have required more effort and

strategies to avoid distraction and maintain accuracy among participants, and perhaps especially so when completed within the context of the larger study which involved several working memory tasks of varying difficulty. Such increased effort and strategizing may have been particularly likely among participants with high levels of worry, resulting in overall better performance for such individuals. Interestingly, Vytal and colleagues (2016) found impaired performance under threat regardless of task difficulty among a sample of individuals with Generalized Anxiety Disorder (GAD), which is characterized by significant and uncontrollable trait levels of worry. They concluded that when performing a highly demanding and difficult task (e.g., with high cognitive load) under threat, GAD patients appeared to devote cognitive resources to reducing anxiety rather than focusing on the task to facilitate performance. My dissertation considered working memory performance among individuals with high trait anxiety more broadly (e.g., not necessarily having a GAD diagnosis), and results are more in line with Vytal and colleagues' original findings (2012; 2013), such that task difficulty may be a key variable in predicting performance for those with varying levels of trait worry. This suggests there may be unique effects of GAD, above and beyond increased worry, which consistently disrupt working memory performance in the context of threat (e.g., regardless of task difficulty).

Such results may also be related to the relatively high levels of self-reported worry within the current sample. Worry was measured via the Penn-State Worry Questionnaire (PSWQ) on which scores can range from 16 to 80, and scores can be classified as “low” (i.e., 16-39), “moderate” (i.e., 40-59), or “high” (i.e., 60-80). The mean worry score in the current study was 57.8 while the median score was 61.5. Over

half of the sample (N=33) reported “High” levels of worry (i.e., scores > 60) while a very small proportion (N=6) reported “Low” levels of worry. Thus, the sample can be described overall, as moderate to high worriers, which might have masked overall effects of worry due to lower variability. High levels of worry in the current sample are perhaps unsurprising, given consistent findings of greater mental health concerns, including anxiety, among the university student population (American College Health Association, 2019; Kang, Rhodes, Rivers, Thornton, & Rodney, 2021). Additionally, data collection for the current study occurred proximally to the COVID-19 pandemic (in the fall of 2022), during which time university students may have been particularly vulnerable to anxiety and distress (e.g., Copeland et al., 2021; Redden, 2020). Moreover, the items on the PSWQ are face valid and many are likely relatable to students in general (e.g., *When I am under pressure, I worry a lot; As soon as I finish one task, I start to worry about everything else I have to do; I worry about projects until they are all done*). This may have contributed to the higher mean and median worry scores within this sample.

Overall, results from the visuospatial and phonological complex change detection tasks provide partial support for the Two Component Model, specifically in terms of the predicted relationship between increased arousal and disrupted visuospatial working memory. A relationship between worry and working memory was also observed, though the nature of this relationship was inconsistent with the Two Component Model, and more in line with a domain-general account. Notably, worry was associated with *improved* performance on both the visuospatial task (i.e., positively correlated with accuracy) and the phonological task (i.e., negatively correlated with

filtering cost for threat and neutral distractors). Such results can potentially be explained by effects of task difficulty which are important according to proponents of the Two Component Model, as well as by early theorizing with respect to the Processing Efficiency Theory, which suggested adaptive effects of worry on performance through increased attention and on-task effort. Future studies should further examine this relationship between worry and both phonological and visuospatial working memory performance. Such research should consider the role of task difficulty as well as potential adaptive effects of worry in terms of aiding task performance, to delineate this relationship more clearly.

Results generally do not support the pattern of domain-general interference proposed by Moran (2016), as overall trait anxiety (i.e., “common anxiety”) was largely unrelated to working memory task performance or was less influential than worry (with respect to filtering cost in the phonological task) and arousal (with respect to accuracy in the visuospatial task). Results from the current study highlight the importance of considering specific domains of anxiety—namely, worry and arousal—as they appear to be uniquely associated with phonological and visuospatial working memory task performance. Considerations of specific domains of anxiety (rather than overall trait anxiety) did, however, reveal support for the role of the domain-general central executive in terms of allocating and directing attention and effort toward cognitive tasks and in terms of its role in the task of filtering. This suggests there are important relationships between components of anxiety (e.g., worry and arousal) with both the domain-specific phonological loop and visuospatial sketchpad, as well as the domain-general central executive. While Moran (2016) alluded to such relationships, it was

argued that worry and arousal are somewhat indirectly related to the domain-general central executive, through common variance shared between them (i.e., *common anxiety*). The results from the complex change detection task in the current study suggest that trait worry, in particular, may be more directly linked to the domain-general central executive than Moran (2016) proposed.

Research Question 2

Research Question 2 sought to determine if the relationship between anxiety and reduced baseline working memory storage capacity is better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT), the domain-specific interference account of the Two Component Model, or whether the two accounts are complementary to one another.

Results from the simple change detection task with visuospatial stimuli (i.e., faces) revealed that the linear mixed effects model with anxiety variables did not fit the data better than the null model (i.e., without anxiety), suggesting the anxiety variables were not important in predicting baseline working memory storage capacity. Such findings conflict with Moran's (2016) conclusion that anxiety is associated with impaired cognitive task performance even when tasks do not require inhibition, thus failing to support either the Two Component Model or PET/ACT. The results of the current study are limited, however, by the fact that accuracy was lower than expected across participants on this visuospatial change detection task, particularly as set size increased. In fact, when considering a set size of 4, in which participants were required to hold 4 faces in working memory to detect if one of the faces changed, accuracy ranged from 0.41 to 0.69 across participants (*Median*= 0.58), with average performance

just above chance level ($Mean = 0.57$). Such task difficulty may have disrupted overall effects of anxiety. Consideration of task performance for a set size of 1 revealed a negative correlation between arousal and accuracy. Thus, on less difficult trials, in which participants were only required to hold one face in working memory, increased arousal was associated with decreased accuracy, as predicted by Moran (2016) and the domain-specific interference account of the Two Component Model. It is likely that effects of anxiety on overall performance on this baseline task were masked by task difficulty, such that all participants regardless of anxiety level showed difficulty on trials as set size increased. Future studies should further consider task difficulty when examining the relationship between anxiety and baseline working memory storage capacity. This may involve limiting set sizes with faces (e.g., 1-2 faces presented on a given trial), or utilizing simpler visuospatial stimuli (e.g., coloured shapes rather than faces) which have been shown to be more easily retained in working memory (e.g., see Alvarez & Cavanaugh, 2004).

Results from the simple change detection task with phonological stimuli (i.e., words) paralleled those of the visuospatial data. Similarly, the anxiety variables were not important in predicting baseline phonological working memory storage capacity. Again, such findings conflict with Moran's (2016) conclusions, and do not lend support for either the Two Component Model or PET/ACT. However, results are limited, although for different reasons. Accuracy on the phonological working memory task was comparable to pilot testing, where accuracy decreased as set size increased, but was consistently above chance level. Specifically, average accuracy in the current study collapsed across set sizes ranged from 0.64 to 0.98 ($M=0.86$) across participants, which

suggests the phonological baseline task was appropriately challenging (unlike the visuospatial baseline task). However, results for this simple change detection task with words are limited by the restricted variability in worry. While results from the visuospatial baseline task provided support for the Two Component Model with a unique relationship between observed between arousal and task accuracy (for a set size of 1), results from this phonological task did not support the parallel relationship between worry and task performance. As previously discussed, the variability in worry was limited in the current study, with most participants reporting moderate to high levels of worry. This restricted range may have masked overall effects of worry in predicting baseline phonological working memory capacity. Future studies should further explore this relationship with a broader sample of low to high worriers, to determine if results support a domain-specific interference account for baseline working memory capacity (e.g., not involving filtering of distracting information).

Research Question 3

Research question 3 sought to determine if worry, arousal, or trait anxiety moderate the relationship between baseline working memory storage capacity and filtering efficiency. For visuospatial data, baseline working memory storage capacity (i.e., accuracy on the simple change detection task) did not predict filtering cost (i.e., accuracy on the complex change detection task) for either neutral or threatening distractors, and there were no significant interactions between the anxiety variables (i.e., arousal and trait anxiety) and baseline working memory storage capacity in predicting filtering cost. Such findings conflict with previous research suggesting that anxiety consistently interacts with working memory span/storage capacity to influence cognitive

task performance (Stout & Rokke, 2010; Qi et al., 2014). Conflicting findings between the current study and previous research could be linked to differences in stimuli between the current study and those used in previous studies. Studies which highlighted this interaction between anxiety and baseline working memory storage capacity (e.g., Stout & Rokke, 2010; Qi et al., 2014) utilized visuospatial stimuli in the form of coloured shapes. However, the current study design drew on more recent work by Stout and colleagues (2013; 2015), which had utilized visuospatial stimuli in the form of faces but did not consider a potential interaction between anxiety and baseline working memory storage capacity. Average accuracy on the baseline change detection task in the current study suggested that working memory storage capacity for faces may be limited, as we observed greater reductions in accuracy with increasing set size on the baseline task with faces than anticipated. This is consistent with Yao and colleagues (2018) who found that the average working memory capacity for faces in their study using a change detection task was less than two faces, which was lower than the capacity estimate for simple stimuli (coloured squares) in their study. Average accuracy on the baseline change detection task for visuospatial stimuli in the current study was less than 68% for set sizes of two (i.e., 67%) and three (i.e., 61%) and approached chance levels for a set size of four (i.e., 57%). Moreover, overall accuracy on the baseline storage task in the current study may not be a robust predictor of filtering efficiency on the complex change detection task due to differences in difficulty level across the two tasks. Average accuracy on the filtering efficiency task was better overall compared to performance on the simple (i.e., baseline) change detection task, likely reflecting the fact that only one face was required to be held in working memory on each trial of the filtering efficiency

task (i.e., while ignoring distracting information), while up to four faces were held in working memory on the baseline task. Previous research highlights the importance of visual information load as well as number of objects in visual short-term memory, such that individuals can retain fewer complex objects (e.g., Chinese characters, random polygons) compared to simpler objects (e.g., coloured squares) and that retention decreases with increased set size (Alvarez & Cavanaugh, 2004). Such findings may help to explain the lower accuracy for increasing set sizes with complex facial stimuli in the current study (Alvarez & Cavanaugh, 2004), and suggest that overall accuracy on the baseline visuospatial task in the current study may not be an ideal indicator of working memory storage capacity due to significantly impaired performance at higher set sizes. Supporting this hypothesis, examination of baseline storage capacity for a set size of 1 showed more of the expected pattern of results in terms of interacting with arousal to predict filtering efficiency. Thus, impaired accuracy on the baseline change detection task (when set size > 1) may have disrupted or masked the overall relationship between baseline storage capacity and filtering efficiency. Future research may benefit from examining the relationship between baseline working memory storage capacity and filtering efficiency with complex face stimuli presented with longer stimulus durations or within smaller set sizes, to limit working memory load and maximize the possibility of retention.

For phonological data, baseline phonological working memory storage capacity consistently predicted filtering cost for neutral distractors (i.e., across set sizes), such that as baseline working memory capacity increased, filtering cost for neutral distractors decreased. This is consistent with previous studies and suggests that individuals with

lower working memory storage capacity may be more likely to store irrelevant or distracting information on filtering tasks, resulting in reduced performance (e.g., Stout & Rokke, 2010; Vogel et al., 2005). In contrast, a relationship between baseline phonological working memory storage capacity and filtering cost for threat distractors (regardless of set size) was not found. This suggests that participants may be equally likely to store irrelevant or distracting stimuli which are threatening in nature, regardless of their baseline working memory storage capacity. This is likely related to the emotionally-valenced and salient nature of such distractors, and may suggest that all individuals (regardless of anxiety level) may be cued to detect threat to some degree. Results from the phonological tasks found no interaction between anxiety (e.g., worry or trait anxiety) and baseline storage capacity in predicting filtering efficiency for threat or neutral distractors. Worry and overall trait anxiety were also not significant predictors of filtering efficiency for threat or neutral distractors. Such findings may again be limited by the restricted range of worry scores within the current sample, such that there were few “low” worriers to fully capture the influence of this variable in predicting filtering efficiency. Nevertheless, these results overall support the importance of baseline working memory storage capacity in predicting filtering efficiency in the face of neutral but not threatening distractors within the context of a working memory task with words.

Research Question 4

Research Question 4 sought to determine if the relationship between anxiety and longer response times (i.e., reduced processing efficiency) is better explained by the domain-general interference account of the Processing Efficiency Theory/Attention Control theory (PET/ACT), the domain-specific interference account of the Two

Component Model, or Moran's (2016) model suggesting that these are complementary accounts.

Results from the baseline and neutral target conditions (i.e., those without distractors) of the filtering change detection task with both visuospatial stimuli (i.e., faces) and phonological stimuli (i.e., words) revealed that the linear mixed effects models with the anxiety variables did not fit the data better overall compared to the null models (i.e., without anxiety). However, there was a significant positive correlation between arousal and response time that was not observed for worry or overall trait anxiety. Notably, this correlation was significant for both the visuospatial and phonological data. According to the PET/ACT theory (Eysenck et al., 2007), processing efficiency is defined as participants' response time to accurately detect changes on a change detection task in which there are no distractors present. Examination of this variable allows for consideration of *how easily* individuals with varying levels of anxiety can temporarily store phonological and visuospatial information in working memory to complete a cognitive task (e.g., detect changes in this stored information; Eysenck et al., 2007). In the current study, individuals with higher levels of arousal took longer to respond on trials in which they produced an accurate response within baseline and neutral target conditions of the visuospatial and phonological complex change detection task. Such findings are consistent with previous research supporting a relationship between increased anxiety and reduced processing efficiency (i.e., longer response times) on working memory tasks, and suggest that heightened arousal is associated with reduced efficiency in terms of storing visuospatial and phonological information in working memory. Together with findings related to Research Question 1,

results suggest that heightened arousal consistently disrupts the visuospatial filtering task, resulting in a greater number of errors in performance/judgment (i.e., reduced accuracy) and longer response times to make accurate judgments. These results extend previous findings, and suggest that the impaired processing efficiency associated with arousal is *not* domain-specific, such that the relationship between arousal and processing efficiency is not specific to visuospatial stimuli. The current results showed that increased arousal is consistently associated with slower response times, regardless of the type of stimuli involved in the task. Results are in line with previous research suggesting that arousal is associated with less spare processing capacity (Hamilton, 1979), and may be linked to involvement of the domain-general central executive system.

General Discussion and Theoretical Implications

Taken together, results of the current study are consistent with aspects of both the Two Component Model and PET/ACT, but underscore that neither of these models is sufficient on their own to account for the relationship between trait anxiety (i.e., worry and arousal) and working memory (i.e., phonological and visuospatial). That is, the current results indicate the relationship between anxiety and working memory involves both domain-specific and domain-general interference. Overall, results are thus most in line with Moran's (2016) proposed model which combined key aspects of the Two Component Model (Vytal et al., 2012; 2013) and Processing Efficiency Theory/Attention Control Theory (PET/ACT; Eysenck et al., 1992; 2007), and extend such previous research to the role of trait (rather than state) levels of arousal and worry in this context. The current results also highlight important caveats to the relationships between arousal and worry with working memory that warrant future consideration.

As predicted by the Two Component Model (Vytal et al., 2012; 2013) and Moran (2016), anxious arousal was found to be directly linked to domain-specific visuospatial storage. Higher arousal predicted impaired performance (i.e., reduced accuracy) on both a baseline change detection task (with a small set size of 1) and a filtering change detection task with faces as stimuli. Arousal was, on the other hand, unrelated to performance on parallel tasks with phonological stimuli (i.e., words). This supports the findings that heightened arousal consistently disrupts visuospatial working memory, likely due to shared neural resources between arousal and visuospatial working memory, and the tendency for arousal to take priority over neural resources given the evolutionary survival advantage. However, arousal was also linked to impaired processing efficiency—defined as increased response time to make accurate judgments, and such relationships were observed for *both* the visuospatial and phonological working memory tasks. This suggests that the relationship between arousal and working memory performance is not solely domain-specific, and that there is a role for domain-general interference as well, specifically in terms of how easily individuals are able to temporarily store phonological and visuospatial information in working memory to complete the cognitive task. The current results imply that heightened arousal is generally very cognitively demanding and consistently interferes with working memory efficiency (e.g., making it more difficult to store information in working memory); however, this may or may not translate to impaired working memory effectiveness (e.g., accuracy). That is, while individuals with heightened arousal are likely to less efficiently (i.e., less quickly, automatically) store information in working memory, they may ultimately be effective (i.e., accurate) on working memory tasks. The key exception to

this is in the case of visuospatial working memory tasks, where heightened arousal is likely to disrupt both efficiency and effectiveness, which underscores the importance of considering both domain-specific and domain-general interference in future work examining arousal and working memory.

In terms of trait levels of worry, results of the current study showed a persistent relationship between worry and working memory task performance *across* stimulus types (i.e., phonological and visuospatial versions of the tasks). This lends support for domain-general interference and the PET/ACT account of the anxiety and working memory relationship. Unexpectedly, worry was consistently associated with *improved* visuospatial and phonological working memory task performance. Theoretically, this suggests that heightened worry may be adaptive in terms of improving working memory task performance.

Such finding of improved task performance in the presence of worry fits with tenets of PET/ACT, which assume that worry is associated with an increase in on-task effort and activities designed to improve performance. This is argued to be due to activation of the domain-general central executive performance which involves a control system within the central executive which is sensitive to failure feedback and allocates greater attention and effort on working memory tasks when such feedback is encountered (regardless of the stimuli involved in the task). However, PET/ACT argues that while heightened worry is linked to improved performance in terms of effectiveness (e.g., accuracy), the increased effort and task-related attention is cognitively demanding and is associated with reduced processing efficiency (e.g., increased response time), a finding which has been empirically supported (e.g., Held et al., 2020; Sari et al., 2017).

The current study found no relationship between worry and processing efficiency, and thus results only partially support the PET/ACT account. Results from the current study should be interpreted with caution due to the limited variability in worry in our sample, as well as the potential role of task difficulty which was not explored. Future studies should address such variables to confirm this proposed domain-general relationship between worry and working memory.

Strengths, Limitations, and Future Directions

While Moran (2016) proposed a model to explain the relationship between working memory (i.e., phonological and visuospatial) and anxiety (i.e., worry and arousal), the current study was, to my knowledge, the first to examine both phonological and visuospatial working memory (in terms of baseline storage capacity, filtering efficiency, and processing efficiency) in a single sample of participants with varying levels of worry and arousal, and directly contributes to our understanding of the complex relationship between anxiety and working memory. Working memory was evaluated not only in terms of filtering efficiency which has shown to be linked to anxiety in previous studies (Stout et al., 2013; 2015), but also as baseline working memory storage capacity and processing efficiency. Baseline working memory storage capacity was not considered in previous work examining the relationship between anxiety and filtering efficiency (Stout et al., 2013; 2015). Results of the current experiment provide partial support for the link between baseline storage capacity and filtering efficiency, such that greater baseline phonological storage capacity was linked to reduced filtering cost for neutral distractors on the phonological filtering task. This suggests that future research should consider baseline storage capacity when examining

filtering efficiency, particularly in further examination of the anxiety and filtering efficiency relationship. As well, the current study considered processing efficiency, or how easily individuals with varying levels of anxiety can temporarily store phonological and visuospatial information in working memory to complete the change detection task, which has been shown to be an important variable to consider in addition to individuals' processing effectiveness or accuracy on working memory tasks (Eysenck et al., 2007). Processing efficiency was not considered in previous work examining the relationship between anxiety and filtering efficiency (Stout et al., 2013; 2015), but results of this dissertation highlight the value of considering this variable. Specifically, the current study found a positive correlation between arousal and response time (i.e., processing efficiency) across both phonological and visuospatial tasks, suggesting that heightened arousal reduces the efficiency with which stimuli are stored in working memory. Such findings underscore the importance of considering processing efficiency in addition to accuracy/processing effectiveness in future research examining the anxiety and working memory relationship.

Moreover, the present work contributes to the existing literature by developing a novel task which appears promising as a measure of phonological working memory and parallels the change detection task utilized with visuospatial stimuli in previous influential work (e.g., Stout et al., 2013; 2015). Key modifications to reflect the nature of the specific working memory store being considered were made to the original visuospatial version of the change detection task (e.g., sequential presentation format instead of simultaneous), and optimal task parameters were considered through pilot testing. Moreover, this phonological variant was shown through pilot testing in the

current work to be a promising approach to examine phonological working memory (refer to Appendix C for details). Although the development of this variant of the change detection task was not a key focus of the current dissertation, this represents a potential contribution to this research area. The feasibility of using this type of task may encourage future researchers to examine *both* phonological and visuospatial working memory when examining the relationships between anxiety and working memory and encourage further exploration of domain-general versus domain-specific interference within such relationships. Nevertheless, this task would benefit from additional examination (e.g., in future experiments) to further validate it as a reliable indicator of phonological working memory.

In terms of anxiety, the current research contributes to the literature by examining trait anxiety as opposed to state anxiety which has been studied more extensively in previous research. Trait anxiety in the current work was conceptualized according to a two-component model and was examined through direct self-report of trait worry and arousal symptoms. Previous work in this area has relied on measuring anxiety through single broadband measures (e.g., State-Trait Anxiety Inventory) and often failed to adequately measure the underlying components of anxiety (e.g., worry, arousal). The current work addressed such limitations by having participants complete measures of trait worry and arousal, and computing a composite score to reflect the overall trait anxiety levels of participants.

Finally, the current work used Linear Mixed Effects (LME) modeling in analyses, which allowed for the examination of anxiety as continuous variables rather than assigning arbitrary cut-off scores to create discrete anxiety groups (as has been

done in much of the previous research in this area). As well, LME allowed for examination of trial-by-trial data rather than collapsing or averaging data across conditions. Together, LME allowed for greater statistical power in the analyses. LME was also beneficial as it is robust to violations of assumptions, and directly accounts for potential sources of error through the addition of random effects such as participant and stimulus variability.

The current study also has several notable limitations, such as the limited variability in self-rated worry levels and greater task difficulty than anticipated for the baseline storage capacity task with visuospatial stimuli (i.e., faces), as previously discussed. Regarding the former, future studies should compare phonological and visuospatial working memory task performance among individuals with a broader range of trait worry ratings. This could involve screening for worry prior to study completion to ensure adequate representation of low and high levels of worry. In terms of the latter, future studies considering working memory storage capacity for faces (i.e., visuospatial stimuli) should further explore the role of task difficulty and may consider a smaller range of set sizes (e.g., 1 to 2, rather than 1-4) to limit task difficulty. Additionally, while the current study replicated previous work examining filtering efficiency with faces (Stout et al., 2013; 2015) which included a stimulus presentation time of 250 milliseconds for faces, future studies may consider utilizing longer stimulus presentation durations which may improve average performance to greater than chance level. Longer stimulus durations may be particularly useful in cases in which set size is manipulated and participants are required to hold more than one stimulus in working memory at a given time. Alternately, researchers may consider using simpler stimuli that may allow

for higher overall performance despite a shorter presentation time; such stimuli have been used in other work examining both anxiety and working memory (Stout & Rokke, 2010; Qi et al., 2014)), suggesting they are also appropriate for this type of investigation. Moreover, results of the current study suggest a potentially important role for task difficulty more broadly which should be further examined in future research. The apparent adaptive role of worry in terms of improved performance on the phonological filtering task in the current study may be attributed to greater task difficulty than anticipated, according to previous research (Vytal et al., 2012). Future studies should thus consider comparing performance among those with varying levels of trait worry when task difficulty is manipulated (e.g., completing both easy and difficult phonological filtering tasks), to determine if worry is associated with impaired task performance on less challenging filtering tasks with words.

The current study is also limited in that potential effects of demographic variables (e.g., age, sex, anxiety disorder diagnosis) were not controlled for in analyses. This is a result of experimenter error during data collection where specific demographic details were not collected (as the demographics questionnaire was missing from the package of questionnaires), and thus the only demographic information available about our sample was from the participant pool, which provided general age (i.e., under or over age 18) and self-reported gender, but this information could not be linked to participant data given appropriate privacy and confidentiality constraints. Future research should attempt to replicate the findings from the current study and determine if the observed relationships between worry and arousal with domain-specific and domain-general working memory persist above and beyond potential effects of key demographic

variables. Notably, a meta-analysis of the relationship between anxiety and working memory capacity (Moran, 2016) found that age did not significantly moderate this relationship, and sex was not included in analyses as a key potential moderator. However, the potential influence of demographics such as age and sex have been considered elsewhere in this literature. For example, a previous study which influenced the current visuospatial task (Stout et al., 2015) found a significant positive correlation between worry and filtering cost which remained significant after statistically controlling for age and sex. The current study did not replicate such correlation, and in fact found the opposite pattern, with higher levels of worry associated with better working memory performance for both phonological and visuospatial stimuli. The current study was unable to confirm that such correlations remain significant after statistically controlling for potential effects of age and sex. Similarly, the current study could not confirm that the relationship between increased arousal and reduced visuospatial task accuracy as well as reduced processing efficiency across visuospatial and phonological tasks is not due to effects of age or sex. As such, future research should statistically control for demographic variables, including age and sex, when further examining these relationships to further confirm the patterns of these effects and whether they are robust when such demographic variables are considered.

Finally, while the current study focused on trait levels of worry and arousal, future research should consider state levels of worry and arousal—that is, situational anxiety which may arise during the cognitive task performance—in this context of visuospatial and phonological filtering task performance. Potential interactions between trait and state anxiety in this context should also be considered. Such considerations will

allow for further delineation of the overall relationship between anxiety and working memory, including potential unique relationships between domain-specific and domain-general working memory with state versus trait levels of worry and arousal. For example, results of the current study revealed that trait levels of worry were significantly positively correlated with accuracy on the visuospatial working memory task and negatively correlated with filtering cost on the phonological working memory task, which may be linked to greater attention to and effort on the task (Eysenck & Calvo, 1992; Eysenck et al., 2005). However, previous research suggested that such greater attention and effort is likely to occur in the presence of failure feedback (e.g., when the participant notices that they are not performing well on the task), which is by nature a state/situational characteristic. Thus, future research should consider whether state levels of worry influence (e.g., mediates, moderates) the observed relationships between trait worry and task performance.

Conclusions

Results of the current study highlight important links between trait arousal and worry with working memory, both in terms of domain-specific phonological and visuospatial working memory components as well as the domain-general central executive. Higher levels of trait arousal were consistently associated with impaired visuospatial working memory, supporting a domain-specific interference account and the competition for limited and shared neural resources between arousal and visuospatial working memory (Moran, 2016; Vytal et al., 2012; 2013). However, domain-general interference was also observed for trait arousal, specifically in terms of processing efficiency or how easily individuals can temporarily store information in working

memory to complete cognitive tasks. Higher levels of trait arousal were associated with impaired processing efficiency (i.e., longer response times to make accurate judgments) for baseline trials of *both* the visuospatial and phonological working memory tasks, supporting domain-general interference. With respect to trait levels of worry, results primarily supported a domain-general relationship, with a persistent relationship between worry and working memory task performance occurring *across* stimulus types (i.e., phonological and visuospatial versions of the tasks). Unexpectedly, however, worry was consistently associated with *improved* visuospatial and phonological working memory task performance. Results appear to support the role of the domain-general central executive control system which receives and responds to failure feedback by allocating greater attention and effort on working memory tasks when performance is impaired, regardless of the type of stimuli involved in the task. Moreover, results suggest that such a control system may be particularly sensitive among individuals with heightened levels of trait worry, and result in greater attention and effort on cognitive tasks among such individuals. Future research should address limitations of the current study, including the restricted range of worry scores, and examine the role of task difficulty in this context to confirm this proposed domain-general relationship between worry and working memory.

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Appendix A

List of facial stimuli

Note: Codes represent file names from the Karolinska Directed Emotional Faces database (Lundqvist et al., 1998)

12 Neutral facial expressions (Half Female/Half Male) for target stimuli:

AF01NES – Female 1, Neutral
AF05NES – Female 2, Neutral
AF06NES – Female 3, Neutral
AF07NES – Female 4, Neutral
AF11NES – Female 5, Neutral
AF30NES – Female 6, Neutral
AM26NES – Male 1, Neutral
AM27NES – Male 2, Neutral
AM31NES – Male 3, Neutral
AM02NES – Male 4, Neutral
AM34NES – Male 5, Neutral
AM35NES – Male 6, Neutral

12 Negative Facial Expressions (Half Fear, Half Anger) for distractor stimuli:

AF01AFS – Female 1, Fear
AF05AFS – Female 2, Fear
AF06AFS – Female 3, Fear
AF07ANS – Female 4, Anger
AF11ANS – Female 5, Anger
AF30ANS – Female 6, Anger
AM26ANS – Male 1, Anger
AM27ANS – Male 2, Anger
AM31AFS – Male 3, Fear
AM02AFS – Male 4, Fear
AM34ANS – Male 5, Anger
AM35AFS – Male 6, Fear

Appendix B

List of word stimuli

12 Neutral words for target stimuli:

Trend
Plain
Lean
Theme
Act
Lift
Wear
Claim
Title
Guide
Pair
Stay

12 Negative words for distractor stimuli:

Fear
Shame
Kill
Fail
Fight
Hate
Panic
Hurt
Fault
Fool
Harm
Wrong

Appendix C: Pilot study

In the literature examining the relationship between anxiety and filtering efficiency, studies have exclusively utilized change detection tasks with visuospatial stimuli (e.g., faces, coloured shapes; Qi et al., 2014; Stout et al., 2013; 2015). Support for the relationship between increased anxiety (e.g., worry) and reduced filtering efficiency in such studies is thus restricted to visuospatial working memory. The broader literature examining the anxiety and working memory relationship highlights important roles for both phonological and visuospatial working memory. As such, the current dissertation aimed to address a gap in the literature by considering the relationship between anxiety and filtering efficiency for phonological stimuli as well as visuospatial. A novel phonological change detection task was thus created to parallel visuospatial tasks utilized in the filtering efficiency literature (e.g., Vogel et al., 2005; Stout et al., 2013; 2015). Creation of this novel task was informed by previous research examining phonological working memory more broadly (e.g., Murray, 1968; Norris et al., 2018; Pegado & Grainger, 2020).

Previous studies have examined phonological working memory performance by presenting verbal material (e.g., words, letters) sequentially in visual format (Murray, 1968; Norris et al., 2018; Pegado & Grainger, 2020). It is argued that such presentation style encourages participants to phonologically code (i.e., read) each verbal item as it appears. Conversely, presenting multiple verbal stimuli simultaneously for storage in working memory has shown to result in visuospatial coding more so than phonological—that is, participants may attempt to store the items in working memory based on the visual characteristics of the letters/words (Pegado & Grainger, 2020).

Due to the novel nature of the phonological version of the change detection task, pilot testing was conducted to ensure the validity and feasibility of this approach. The goals of this pilot project were to determine the appropriate length of presentation of each stimulus in the sequential presentation (i.e., 250, 500, or 1000 milliseconds); to determine the most effective set size variation to obtain variable performance on this task (e.g., 2-6 words versus 1-4) and to examine the difficulty of detecting changes with word stimuli. For set sizes and stimulus duration, I sought to determine a subset of set sizes (and a stimulus duration) that ensures variability in performance across participants. In one of the original studies with a visuospatial change detection task, Vogel and colleagues (2005) found ceiling effects in performance for small set sizes (e.g., set size = 1), and decreasing performance with increasing set size. While it was not important for the phonological task performance of participants in the current study to be identical to that of the visuospatial task, I used pilot testing of the phonological task to ensure that participants' responses did not exhibit ceiling and/or floor effects at all set sizes (e.g., 100% performance at all set sizes would suggest that the task is too easy, whereas 50% performance at all set sizes would suggest that the task is too difficult and participants have guessed when making their responses). I sought to determine the appropriate duration to allow for variability in performance, such that the average performance across set sizes is approximately 80%. This target value is better than chance (50%) and allows for variability in performance across set sizes (e.g., with better performance for smaller set sizes and vice versa), while reducing ceiling and floor effects.

Participants in the pilot study were also asked to complete a questionnaire following the change detection task, which asked them to identify the strategies they used during the task. This questionnaire was developed for use in the current study and aimed to further verify participants' use of phonological coding of verbal stimuli (i.e., read each word as it appears; verbal rehearsal during delay period) rather than visuospatial coding (e.g., remembering visual characteristics of the words).

Participants

Forty-four undergraduate students from the University of New Brunswick participated in the pilot study in exchange for introductory psychology course credit. Participants ranged in age from 17 to 28 ($M = 19.8$). A total of 37 participants self-reported as "female", 6 as "male", and 1 as "other". All participants reported English was their first language.

Measures

Demographics. All participants completed a demographics questionnaire that asked them to self-report their age and sex, as well as whether English was their first language (i.e., Yes/No).

Strategies Questionnaire. Participants were asked to complete a self-report questionnaire regarding their use of verbal versus visual strategies during the working memory task. This scale was created for use in the current study, and included four items: (1) *On each trial I read each word as it appeared*; (2) *On each trial I repeated the target word(s) to myself during the delay period*; (3) *On each trial I tried to remember how the words looked on the screen as they were presented*; and (4) *On each*

trial I made note of the visual characteristics of the words (e.g., the “shape” of the words, word length) and used this information to detect changes. For each item, participants responded on a Likert scale with the following designations: 0-Never, 1-Rarely, 2- Sometimes, 3-Frequently, and 4-Very Frequently.

Working Memory. The baseline phonological change detection task, described in the main study of the dissertation, was manipulated for evaluation in the pilot study. The design (e.g., word stimuli, presentation parameters) of this task was identical to the baseline phonological change detection task outlined previously (see **Method: Measures and Tasks**). However, the key variables of interest (i.e., stimulus duration, number of words or set size) were manipulated to examine effects on participants’ accuracy and to determine the most effective parameters for the phonological change detection task in the main study. Specifically, Stimulus Duration was manipulated such that words were presented for 250 milliseconds, 500 milliseconds, or 1000 milliseconds on a given trial. Additionally, Set Size was manipulated such that two, three, four, five, or six words were presented on a given trial. Each of the five set sizes was presented in each of the three stimulus duration conditions a total of 12 times, for a grand total of 180 trials.

Procedure

Due to the COVID-19 pandemic and restrictions to in-person data collection, the pilot testing was conducted through virtual/remote data collection methods. Participants were invited to join the experimenter via video chat software (i.e., Microsoft Teams), where they were informed of the study and provided a link to download the experiment

materials via E-Prime Go (Psychology Software Tools, Pittsburgh, PA)⁹. The experimenter provided instructions for each component of the experiment and was present (via virtual video chat connection) for the duration of the experimental session. Participants were first asked to complete the working memory capacity task. Following this, they were asked to complete the Demographics and Strategies questionnaires. Participants were then debriefed and compensated, and their experimental data was automatically uploaded to the Attention and Memory Lab's E-Prime Go online account.

Results

Strategies

Participants' responses to the strategies questionnaire were examined with descriptive statistics. The majority of participants reported using verbal strategies throughout the task. Specifically, 95.4% of participants reported they "Frequently" (22.7%) or "Very Frequently" (77.2%) read each word as it appeared, and 56.8% reported they "Frequently" (27.3%) or "Very Frequently" (29.5%) repeated the target word(s) to themselves during the delay period. In contrast, use of visual strategies was less commonly reported, with 50% of participants reporting that they "Frequently" (27.3%) or "Very Frequently" (22.7%) tried to remember how the words looked on the screen as they were presented, and 31.8% of participants reporting that they "Frequently" (27.3%) or "Very Frequently" (4.5%) made note of the visual

⁹ E-Prime Go is a component of E-Prime 3.0 which allows for remote data collection whereby experimenters can host experiments on the E-Prime website, share the link with participants, and have participants' data automatically uploaded to their E-Prime account upon completion.

characteristics of the words (e.g., the “shape” of the words, word length) and used this information to detect changes.

Working Memory

Average accuracy in the verbal change detection task was computed for each participant within each condition. Average accuracy on the baseline change detection task with words was examined using a 5(Set Size: 2/3/4/5/6) x 3(Stimulus Duration: 250 ms/500 ms/1000 ms) repeated-measures ANOVA. Mean accuracy scores are reported in Table A1. Mauchly’s test revealed a violation of sphericity for Set Size ($W = .234, p < .001$) and the Set Size x Stimulus Duration interaction ($W = .153, p < .001$). As such, Greenhouse-Geisser corrections are reported for these effects. The assumption of sphericity was met for Stimulus Duration ($W = .957, p = .401$). A significant interaction emerged for Set Size x Stimulus Duration [$F(5.891, 253.326) = 3.351, p = .004, \eta^2 = .072$]. A visual depiction of the interaction is presented in Figure A1. Pairwise comparisons were conducted to examine the interaction. Comparisons revealed that accuracy generally decreased with increasing set size across stimulus durations. However, there were non-significant differences between similar set sizes within each duration: for 250 ms, set sizes of two and three as well as four and five produced statistically equal accuracies ($p = .70$ and $p = 1.00$, respectively); for 500 ms, set sizes of two, three and four were statistically equivalent (p ’s $> .08$) as were set sizes five and six ($p = .16$); for 1000 ms, set sizes of two and three, as well as three and four, were not statistically different ($p = 1.00$ and $p = .08$, respectively). Additionally, comparisons revealed that accuracy was significantly better for the 500 ms duration than the 250 ms duration for a set size of four ($p < .01$), and accuracy was significantly better for the 500

ms duration than the 1000 ms duration for a set size of 6 ($p < .02$). No other significant differences in stimulus duration as a function of set size emerged.

Discussion

The pilot study examined the feasibility of a sequentially presented verbal change detection task. More specifically, the goals were to determine an appropriate length of presentation of each stimulus in the sequential presentation, an effective set size variation to obtain variable performance on this task, and to examine the difficulty of detecting changes with word stimuli. Results from the strategies questionnaire supported the use of this task to measure phonological working memory, as participants reported using verbal working memory strategies more so than visual strategies (i.e., reading each word as it appears more so than relying on the visual characteristics of the word; use of verbal rehearsal).

Overall accuracy on this task was high (>70% across all conditions). However, greater variability in accuracy emerged as set size increased. In keeping with results from Vogel and colleagues (2005), performance for smaller set sizes (e.g., set sizes of 2 and 3) approached ceiling effects (Mean Accuracy >0.95), while accuracy decreased with increasing set size (i.e., set sizes of 4, 5, and 6). Such results are expected and reflect increasing demands on working memory (and a greater likelihood of making errors) with a greater number of items to remember.

The proposed verbal change detection task thus appears to be an effective approach to examine verbal working memory. Results of the pilot testing indicate that a subset of set sizes ranging from 2 to 5, along with a stimulus duration of 250 milliseconds, would allow for variability in performance and thus serve well for the

Table A1. Mean accuracy rate by Set Size and Stimulus Duration.

Stimulus Duration	Set Size	Mean (SD)
250 ms	2	.979 (0.05)
	3	.956 (0.07)
	4	.895 (0.11)
	5	.875 (0.09)
	6	.746 (0.15)
500 ms	2	.992 (0.03)
	3	.975 (0.05)
	4	.960 (0.08)
	5	.855 (0.12)
	6	.796 (0.13)
1000 ms	2	.983 (0.04)
	3	.979 (0.04)
	4	.932 (0.11)
	5	.832 (0.13)
	6	.712 (0.13)

Note: Standard deviations are reported in parentheses.

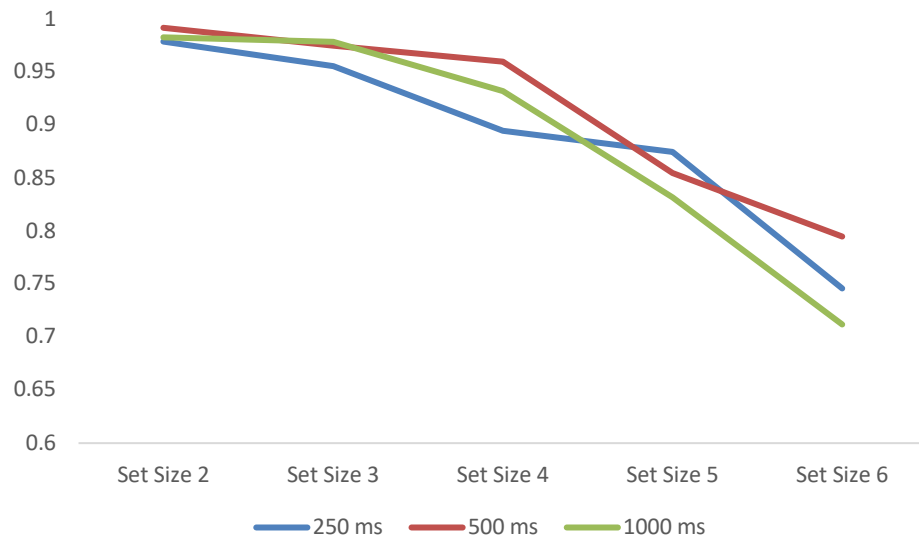


Figure A1. Average accuracy by Set Size (2/3/4/5/6) and Stimulus Duration (250 ms/500 ms/1000 ms).

examination of baseline verbal working memory capacity in the main study. More broadly, the current results contribute to a gap in the working memory and anxiety literature by providing support for a novel method of examining phonological filtering efficiency.

Curriculum Vitae

EDUCATION

- 2017 – Present **Ph.D., Clinical Psychology***
University of New Brunswick (UNB), Fredericton, NB
*CPA Full Accreditation
Dissertation: Elucidating the relationship between anxiety and working memory: An examination of domain-general and domain-specific interference.
Supervisor: Biljana Stevanovski, Ph.D.
Anticipated graduation: October 2024
GPA: 4.2/4.3
- 2015 – 2017 **MA Applied Psychology**
Laurentian University, Sudbury, ON
Thesis: The role of attentional resources in facial expression processing among individuals with high trait anxiety: An Event-related potential study
Supervisors: Joël Dickinson, Ph.D.
Annie Roy-Charland, Ph.D., L. Psych
Graduation: October 2017
GPA: 4.28/4.3
- 2011 – 2016 **Bachelor of Science (Hons), Psychology, Minor in Biology**
Cape Breton University, Sydney, NS
Thesis: The effect of the local noun on subject-verb agreement in adults
Supervisor: Erin Robertson, Ph.D.
Graduation: May 2015
GPA: 4.25/4.3

CLINICAL ACTIVITIES

CLINICAL INTERESTS

Assessment and treatment of child and adolescent psychopathology with particular interest in anxiety, depression, neurodevelopmental disorders, transgender health, and comorbid health and mental health concerns; psychoeducational and psychodiagnostic assessment; individual and group intervention; transdiagnostic and integrative intervention (CBT, DBT, ACT, family-based and parent-training approaches).

CLINICAL TRAINING EXPERIENCES

September 2022 – August 2023 **Pre-Doctoral Residency in Clinical Health Psychology**
Child and Adolescent Stream
University of Manitoba/Shared Health Manitoba,
Winnipeg, MB

Major Rotation in Intervention (September 2022-February 2023)

Included approximately 12 individual cases, ranging in age from 4-16 and characterized by overlapping mental health, health, and developmental-related concerns. This included: GI-related diagnoses (e.g., IBS, rumination disorder, Eosinophilic Esophagitis) further complicated by significant anxiety; diabetes and comorbid behaviour concerns (e.g., resistance to diabetes management) as well as significant needle and venipuncture phobias; treatment of encopresis in the context of other developmental concerns; and behavioural concerns and parent support/training in the context of ASD. Treatment modalities included CBT, ACT, and DBT, as well as influences from the Mind-Body Connection treatment protocol created by Dhariwal et al. (2019; BC Children's Hospital). I also co-led a 6-session ACT group for adolescents with chronic pain and am currently co-leading a 6-session Mind-Body Connection Group for adolescents with somatization. Psychometric assessment has also been incorporated into this rotation, including within the assessment-to-treat model of our services, as well as a more formal assessment completed with a young client with encopresis—to better understand developmental and cognitive abilities to facilitate treatment planning and school program planning.

Supervisor: Dr. Jennifer Ducharme, Ph. D., C. Psych

Long-Term Rotation with the Child Protection Centre (September 2022 – August 2023)

Caseload of 2-3 long-term child psychotherapy cases using a Trauma-Focused CBT approach. Currently working with an adolescent (age 15) refugee with a significant trauma history associated with her flee from her country of origin and will soon begin work with a 5-year-old boy with a recent history of sexual abuse. Treatment involves individual intervention with clients, consultation with and support for caregivers and parents, as well as informal assessment of trauma and co-morbid mental health concerns.

Supervisor: Dr. David Willoughby, Ph.D., C. Psych

Minor Rotation with the Crisis Response Centre (September 2022 – February 2023)

Co-facilitated a 16-week therapy group for adults who were recently in crisis and made a suicide attempt (i.e., Living with Hope Group – combining CBT, DBT, mindfulness, and ACT skills). Rotation also included opportunity to consult with two interdisciplinary crisis teams, to observe support groups offered at a local Crisis Stabilization Unit and provide feedback and support to facilitators, and to conduct efficient safety and suicide risk assessments to adult clients seeking services through the Urgent Follow-Up Intensive Treatment Team at the Crisis Response Centre.

Supervisor: Dr. Christine Henriksen, Ph.D., C. Psych

Major rotation in Assessment (March 2023 – August 2023)

To include a minimum of 10-12 comprehensive assessments with integrative reports primarily in an outpatient setting (through the Child and Adolescent General Consult Team). Will involve psychoeducational and psychodiagnostic assessments related to various presenting concerns, including specific learning disorders, ASD, ADHD, intellectual disorder, and mental health disorders. Will also involve brief consultation and assessment with inpatient psychiatry to inform differential diagnosis (e.g., for psychosis, mood disorders, cognitive ability). As part of this rotation, I will be participating in a one-week Jordan's Principle trip to northern Manitoba (i.e., Swan River) to complete assessments within two rural First Nations communities.

Supervisor: Dr. Lauren Chance, Ph.D., C. Psych.

Minor Rotation with Geropsychology (March 2023 – August 2023)

To carry a caseload of 2-3 individual therapy cases within a geriatric population (age 65+) seeking support for a wide-range of mental health and related concerns (e.g., anxiety, depression, stress, relationship difficulties, cognitive decline). Treatment primarily expected to involve a combination of CBT and ACT approaches.

Supervisor: Dr. Lesley Koven, Ph. D., C. Psych

July 2021 – August 2022

Assessment for Children and Adolescents

Dr. Hilary Cartwright and Associates, Fredericton, NB

Activities: Conducting in-person psychoeducational and psychodiagnostic assessments for a total of 10 children

and adolescents (6-17 years old). Conducted interviews, administered rating scales and various cognitive, academic, and other relevant tests, wrote integrative reports, and provided feedback. Administering rating scales and observed Autism Diagnostic Observation Schedule administrations, assisted with scoring and writing integrative reports, and provided feedback. Receiving individual and group supervision.
Presenting concerns/Diagnoses: ASD, ADHD, SLDs, anxiety.

Supervisor: Hilary Cartwright, Ph.D., L. Psych.

Intervention for Children and Adolescents

Dr. Hilary Cartwright and Associates, Fredericton, NB

Activities: Conducting therapy with children and adolescents for general mental health concerns (e.g., anxiety, depression, trauma), behavioural challenges, and relationship concerns. Involved working closely with parents to manage their child's symptomology. Received individual and group supervision.

Supervisor: Hilary Cartwright, Ph.D., L. Psych.

January- April 2021

Advanced Practicum: Integrated Services Delivery Child & Youth Team

Horizon Health Network, Fredericton, NB

Intervention

Activities: Conducted in-person and telepsychology interventions for children and adolescents with various mental health concerns (e.g., anxiety, depression, self-harm, ASD, ADHD). Use of the Unified Protocol Transdiagnostic treatment protocol with two adolescent clients (age 13/14). Observation and co-facilitation of a Dialectical Behaviour Therapy group with adolescents and their parents/caregivers. Consultation with interdisciplinary team members including social workers, guidance counsellors, and psychiatrists. Received regular individual supervision.

Supervisor: Amy Otteson, MA, L. Psych.

Assessment

Activities: Observed (1) and conducted interviews (2) to assess for gender dysphoria, and wrote referral letters for treatment (e.g., puberty blockers and hormone therapy), where appropriate. Conducted a psychodiagnostic

assessment for Body Dysmorphia (client age 15), wrote an integrated report, and provided feedback.
Supervisor: Amy Otteson, MA, L. Psych.

May – Dec 2019

Practicum in Intervention: Child Therapy

Psychological Wellness Centre, UNB, Fredericton, NB

Activities: Provided weekly supportive counseling and basic cognitive behaviour therapy and parent training interventions for child and adolescent clients (6-18 years old) with anxiety, depression, substance abuse, disruptive behaviour, family conflict/disruption, and Tourette's disorder. Wrote intake, progress notes, and treatment summaries. Completed one psychodiagnostic assessment (diagnoses included Social Anxiety Disorder and Generalized Anxiety Disorder) and wrote assessment report.

Supervisor: Meghan Richards, Ph.D., L. Psych.

Jan – Sept 2019

Practicum in Intervention: Adult Therapy

Psychological Wellness Centre, UNB, Fredericton, NB

Activities: Provided weekly supportive counseling with basic cognitive behaviour therapy to adult clients (18-35 years old) with anxiety, depression, emotion dysregulation, grief, and interpersonal problems. Wrote intake and progress notes, and treatment summaries. Completed one psychodiagnostic assessment (diagnoses included cannabis use disorder, excoriation disorder, social anxiety disorder) and wrote assessment report.

Supervisor: David Colquhoun, Ph.D., L. Psych.

May 2018 – Jan 2019

Structured Clinical Interviewing Experience

UNB, Fredericton, NB

Activities: Conducted pre- and post-intervention assessments using the Structured Clinical Interview for the DSM-5 (SCID-5) with adults (20-65 years old) for a randomized control trial study comparing the efficacy of CBT for anxiety sensitivity to disorder-specific CBT. Provided case conceptualization for diagnostic considerations. Received individual supervision.

Supervisor: Janine Olthuis, Ph.D., L. Psych.

May – Dec 2018

Practicum in Assessment: Child Assessment

Psychological Wellness Centre, UNB, Fredericton, NB

Activities: Conducted (2) comprehensive child and adolescent psychoeducational assessments (clients ages 12 and 8). Administered and scored assessment measures.

Wrote comprehensive reports. Provided feedback to clients. Received individual supervision.
Presenting concerns/Diagnoses: ADHD, SLD in reading and written expression
Supervisor: Meghan Richards, Ph.D., L. Psych.

Jan – July 2018

Practicum in Assessment: Adult Assessment

Psychological Wellness Centre, UNB, Fredericton, NB
Activities: Conducted (3) comprehensive adult psychoeducational assessments (clients ages 19, 27, and 32). Administered and scored assessment measures. Wrote comprehensive reports. Provided feedback to clients. Received individual supervision.
Presenting concerns/Diagnoses: SLDs, ADHD, Avoidant-Restrictive Food Intake Disorder (ARFID)
Supervisor: Meghan Richards, Ph.D., L. Psych.

May – August 2017

Advanced Practicum: Child & Adolescent Mental Health and Addictions

Nova Scotia Health Authority- Eastern Zone, Sydney, NS

Intervention

Activities: Observed intervention of children and adolescents with various mental health concerns (anxiety, depression, OCD, tics and Tourette's Disorder, ADHD). Provided CBT for anxiety for one child client. Co-facilitated a CBT for anxiety group (i.e., CoolKids/CHILLED) with adolescents and their parents. Co-facilitated a support group for parents of children with intense emotions, which provided psychoeducation and supported parents in the use of DBT skills. Consulted with other interdisciplinary team members, including social workers, psychiatrists, and behaviour interventionists. Provided a psychoeducation session to interdisciplinary team members regarding executive functions and related behavioural strategies to use with clients in treatment. Received individual, group, and peer supervision.

Primary Supervisor: Betsy Marcin, Ph.D., R. Psych.

Secondary Co-supervisors: Elyse Boudreau, Ph.D., R. Psych,
Laura MacNeil, M.A., R.Psych
Danielle Shelley, P.h.D., R. Psych

Assessment

Activities: Assisted in intake interviews for children and adolescents with various mental health concerns (e.g., anxiety, depression, OCD, behavioural and conduct concerns, ADHD) and wrote summary reports using the Choice and Partnership Approach (CAPA) framework. Assisted in assessments of ADHD, including conducting interviews with parents and interpreting rating scales, writing integrative reports and providing feedback. Observed Autism Diagnostic Observation Schedule administrations, assisted with scoring and providing feedback.

Primary Supervisor: Betsy Marcin, Ph.D., R. Psych.

Secondary Co-supervisors: Elyse Boudreau, Ph.D., R.

Psych,

Laura MacNeil, M.A.,

R.Psych

Danielle Shelley, P.h.D., R.

Psych

Program Evaluation

Activities: Conducted a program evaluation study examining the effectiveness of the CBT group for anxiety with teens and their parents. Collected pre- and post-intervention ratings of anxiety using the Screen for Child Anxiety Related Disorders (SCARED). Analyzed data, wrote a summary report, and disseminated the results to group facilitators and other mental health professionals working on the team.

Supervisor: Betsy Marcin, Ph.D., R. Psych.

CLINICAL SUPERVISION EXPERIENCE

April 2023 – August 2023
opportunity

Supervision of Practicum Student- “mini-practicum”

To provide supervision for 1 graduate student in the University of Manitoba’s Clinical Psychology program. Will involve the student directly observing a minimum of 1 complete psychoeducational assessment (e.g., review of referral/chart, intake, test administration, feedback) through the Clinical Health Psychology program; to provide one-on-one supervision.

Student/Supervisee: Caelan Budhoo, BSc.

January 2021 – August 2022

Senior Student Supervisor

Psychological Wellness Centre, UNB, Fredericton, NB

Activities: Assisted five first-year clinical doctoral students in learning to administer the Woodcock Johnson Test of Achievement- 4th edition. Provided group education sessions as well as individualized practice sessions and feedback (completed February 2020).

Co-supervision of 5 first-year clinical doctoral students completing ten psychoeducational assessments with children and adolescents. Responsible for conducting intake sessions with students; observing testing (live and videotaped); checking test scoring; providing individual and group supervision regarding skill development; assisting with case conceptualization; editing and providing feedback on integrative report writing; receiving individual supervision regarding my own supervision.

Supervisors: Meghan Richards, Ph.D., L. Psych.
Janine Olthuis, Ph.D., L. Psych.

September – December 2020 **Clinical Supervision Practicum**

Psychological Wellness Centre, UNB, Fredericton, NB

Activities: Supervision of one full psychoeducational assessment by a first-year student; attended intake; observed testing; reviewed scoring and interpretation; provided feedback to student on assessment; completed readings regarding clinical supervision; group and individual supervision discussions and role plays.

Primary Supervisor: Meghan Richards, Ph.D., L. Psych

CLINICAL WORKSHOPS and SEMINARS

Gibson, A. (2023, June 22). Psychological Consultation. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.

Unger, J., & Warren, M. (2023, June 15). Kids and Screentime. Clinical Health Psychology Grand Rounds attended virtually.

Dupasquier, J. (2023, June 15). Working with Gender Diverse Adults. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.

Tung, A. (Peer Connections Manitoba; 2023, June 8). Hearing Voices. Workshop attended virtually through Peer Connections Manitoba.

Koven, L., & Millikin, C. (2023, June 1). Aging II: Neurocognitive concerns and family adaptations. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.

Sexton, L., & Koven, L. (2023, May 25). Aging I: Considerations for psychotherapy with older adults. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.

Johnson, E. (2023, May 11). Clinical Supervision I. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.

- Westmacott, R. (2023, May 4). Emotion-Focused Therapy. Clinical Health Psychology Resident Academic Half Day seminar attended in-person at the University of Manitoba.
- Cantin, D. (2023, April 27). Working with Northern communities. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Wiebe, K., & Wallbridge, H. (2023, March 16). MAiD and Mental Disorders as the sole medical condition: Considerations for Psychological Practice. Clinical Health Psychology Grand Rounds attended virtually.
- Patel, R. (2023, March 9). Neuropsychological rehabilitation: An overview of clinical service, trends, and current research. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Kinley, J. (2023, February 9). Radically Open Dialectical Behaviour Therapy. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Busch, C. (2023, February 9). *Turning uncertainty into opportunity: How the science of serendipity can help you create joy, meaning – and "smart luck"*. Dr. Robert Martin memorial speaker seminar attended virtually through the Clinical Health Psychology department.
- Marcoux, M. (2023, February 2). Psychopharmacology. Clinical Health Psychology Resident Academic Half Day seminar attended in-person at the University of Manitoba.
- Sabourin, B., & El-Gabalawy, R. (2023, January 26). Online treatment for chronic pain. Clinical Health Psychology Grand Rounds attended virtually.
- Tkachuk, G. (2023, January 26). Acceptance and Commitment Therapy II. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Tkachuk, G. (2022, December 15). Acceptance and Commitment Therapy I. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Murphy, C. (2022, December 8). Early Psychosis: Intervention. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Alcolado, G. (2022, November 17). Professionalism in Psychology. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Farb, N. (University of Toronto; 2023, November 21). Stress, sensation, & wellbeing: A neuroscience-informed account of mental balance. Edge of Science presentation attended virtually through the University of Manitoba.
- Unger, J. (2022, November 3). Professional and Ethical Issues with Children and Adolescents. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Murphy, C. (2022, October 27). Early Psychosis: Assessment. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Horton, J. (2022, October 20). *Rewiring the motherboard and countering burnout: How mindfulness can become a way of life*. Clinical Health Psychology Grand Rounds attended virtually.
- Henriksen, C. (2022, October 13). Suicide Intervention. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Ducharme, J. (2022, October 6). Suicide Risk Assessment. Clinical Health Psychology Resident Academic Half Day seminar attended in-person at the University of Manitoba.

- Abdulrehman, R. (2022, September 29). Culturally sensitive therapy. Clinical Health Psychology Resident Academic Half Day seminar attended virtually.
- Fellner, K. (2022, September 15). *Indigenous healing*. Clinical Health Psychology Grand Rounds attended virtually.
- Petersen, J., & Twohig, M. (Juniper Mental Health; 2022, October 21). Acceptance and Commitment Therapy with Children and Adolescents. Workshop attended online.
- Ares, I., & Overington, L. (The Royal Ottawa; 2022, May 13). Working with Concurrent Disorders. Workshop attended online through the University of New Brunswick.
- Olthuis, J., & Savoie, J. (University of New Brunswick, Horizon Health Network; 2021, October 29th).
Practicing Self-Care: The Why, The What, and The How. Three-hour workshop attended online through the University of New Brunswick.
- Cohen, J. & Couture, M.E. (Nova Scotia Health Authority; 2020, April 24). *Dialectical Behaviour Therapy*. Six-hour workshop attended online through the University of New Brunswick.
- Poulin, C. (University of New Brunswick; 2020, September 25). *What does P-SEC and feminism got to do with Clinical Psychology, BIPOCS, Intersectionality and EDI?* Three-hour workshop attended online through the University of New Brunswick.
- Otteson, A. (Horizon Health; 2020, October 23). *Suicide Risk Assessment and Intervention*. Six-hour workshop attended online through the University of New Brunswick.
- O'Sullivan, L. (University of New Brunswick; 2021, March 19). Negotiating Intimate Relationships in the Digital Age. Three-hour workshop attended online through the University of New Brunswick.
- Campbell, M. (University of New Brunswick; 2019, November 29). Program Evaluation. Three-hour workshop attended at the University of New Brunswick.
- LaChapelle, D. (University of New Brunswick; 2020, February 21). Pain Management. Three-hour workshop attended at the University of New Brunswick.
- Sauer-Zavala, S. (*Boston University*; 2019, March 18). The Unified Protocol for Transdiagnostic Treatment of Emotional Disorders. Six-hour workshop attended at the University of New Brunswick.
- Savoie, J. (*Stan Cassidy Centre for Rehabilitation*; 2019, March 15). Making Heads or Tails of Concussions. Three-hour workshop attended at the University of New Brunswick.
- Otteson, A. (*Otteson Psychological Services*; 2018, November 16). Suicide Risk Assessment and Intervention. Six-hour workshop attended at the University of New Brunswick.
- D'Entremont, B. (*University of New Brunswick*; 2018, October 26). Parent Management Training. Three-hour workshop attended at the University of New Brunswick.
- Williams, Diane. (*Elsipogtog Mental Health and Addictions*; 2018, February 23). Working with First Nations Individuals. Six-hour workshop attended at the University of New Brunswick.

- Palmer, M. (*University of New Brunswick*; 2018, February 22). Working with clients with Autism Spectrum Disorders (ASD). Three-hour workshop attended at the University of New Brunswick.
- Sears, H. (*University of New Brunswick*; 2018, January 26). Working with Grief. Six-hour workshop attended at the University of New Brunswick.
- Ronis, S. (*University of New Brunswick*; 2017, December 1). Working with Families. Six-hour workshop attended at the University of New Brunswick.
- McIssac, L., & MacNeil, L. (Nova Scotia Health Authority; 2017, August 15). Clinician's Guide to Suicide Risk Assessment. Workshop attended at Child and Adolescent Mental Health and Addiction Services within the Nova Scotia Health Authority, Eastern Zone.
- Maté, G. (2016, May 5-6). *Grounding Trauma: The Essence of Trauma in Addiction and Illness with Dr. Gabor Maté*. Two-day workshop attended through CAST Canada, Ottawa, Ontario.
- Lafrance-Robinson, A. (2016, March 31). *Carer's Workshop for Teachers*. Assistant workshop host through the Rainbow District School Board, Sudbury, Ontario.
- Eklblad, A. (2015, September 18-19). *Dialectical Behavioural Therapy Training Seminar*. Two-day workshop through the Oshawa Psychotherapy Training Institute, Oshawa, Ontario.

PROFESSIONAL DEVELOPMENT

PROFESSIONAL AFFILIATIONS

- | | |
|----------------|--|
| 2016 – 2022 | Canadian Society for Brain, Behaviour, and Cognitive Science (CSBBCS)
<i>Student Member</i>
<i>Associate Departmental Representative for UNB (2020-2022)</i> |
| 2014 – Present | Canadian Psychological Association (CPA) |

DEPARTMENTAL ACTIVITIES

- | | |
|-----------------------|---|
| June 2019 – June 2022 | UNB Undergraduate Relationships and Engagement Representative for Psychology Graduate Students
<i>Activities:</i> Act as a graduate liaison to undergraduate students in the psychology department; Providing information regarding the UNB psychology graduate program or getting into graduate school in general. |
| June 2018 – June 2019 | Vice President Administration of the UNB Psychological Association of Graduate Students
<i>Activities:</i> Assisted in planning and facilitating orientation for incoming graduate students, as well as faculty-student meet and greets and various student activities throughout the year. |

COMMUNITY ACTIVITIES

2019	Student Volunteer, New Brunswick Brain Bee for High School Students <i>Activities:</i> Facilitated an activity regarding neurological disorders where students were required to simulate an assessment interview to find the correct diagnosis of mock patients.
2018	Student Volunteer, UNB Graduate Student Association Orientation <i>Activities:</i> Welcomed incoming graduate students and disseminated welcome packages.
2014-2015	Cape Breton District Health Authority Volunteer <i>Activities:</i> Conducted literature searches on various mental health issues and prepared information packages for patients and/or caregivers being treated within the Child and Adolescent Mental Health and Addictions team in the Cape Breton District.
2014-2015	Tutor and Mentor, Youth Peer Program <i>Activities:</i> Provided educational and social support to at-risk youth through mentorship and tutoring in several subject areas. Participated in one-on-one and group activities to promote self-esteem development and positive social interactions.
2012- 2015	Member of Cape Breton University's Student Union Psychology Society <i>Activities:</i> Working to raise awareness and reduce the stigma associated with mental illness through organization of events within Cape Breton University and the surrounding community. Fundraising in support of local charities supporting those with mental illness.

SCHOLARSHIPS, HONOURS, AND AWARDS

2019- 2021	Board of Governor's Merit Awards for Graduate Studies \$9,000
2018 – 2022	Social Sciences and Humanities Research Council of Canada (SSHRC) Doctoral Fellowship \$80,000
2018-2021	New Brunswick Innovation Foundation Award NBIF \$27,000
2018-2020	Faculty of Arts Graduate Assistantship UNB \$44, 385
2017-2021	Dr. William S. Lewis Fellowship UNB \$100,000
2017	Ontario Graduate Scholarship (OGS) University of Ottawa (declined)

	\$15,000
2017	Canadian Psychological Association Certificate of Academic Excellence Laurentian University
2016	Ontario Graduate Scholarship (OGS) Laurentian University
	\$15,000
2016	Laurentian University Graduate Fellowship
	\$1,000
2015-2016	SSHRC Canadian Graduate Award
	\$17,500
2015	Governor General Academic Silver Medal
	\$1,000
2014	Natural Sciences and Engineering Research Council (NSERC) Undergraduate Student Research Award
	\$7,500
2015	Canadian Psychological Association Certificate of Academic Excellence Cape Breton University
2011-2015	Cape Breton University President's Scholarship
	\$20,000
2011-2015	Dean's List with Distinction Cape Breton University Honours Society
2011	Lieutenant Governor's Scholarship
	\$1,000
2011	Queen Elizabeth II Medal

TEACHING ACTIVITIES

TEACHING INTERESTS

Memory and cognition; clinical psychology; psychopathology

GUEST LECTURES

2020 & 2019	PSYC3151: Basic Research Seminar
	UNB, Fredericton, NB
	<i>Activities:</i> Gave two invited guest lectures on how to create an effective curriculum vitae
	<i>Instructor:</i> Biljana Stevanovski, Ph.D.
2018	PSYC 2603: Foundations of Memory and Cognition
	UNB, Saint John, NB
	<i>Activities:</i> Gave an invited guest lecture on working memory
	<i>Instructor:</i> Darren Piercey, Ph.D.
2016	PSYC 1105: Introduction to Psychology
	<i>Activities:</i> Gave two invited guest lectures on anxiety
	<i>Instructors:</i> Joël Dickinson, Ph.D.
	Cynthia Whissell, Ph.D.

TEACHING ASSISTANTSHIPS

Sept 2020- April 2021	PSYC2103: Quantitative Research Methods UNB, Fredericton, NB <i>Activities:</i> Graded lab reports and provided feedback to students regarding appropriate research paper format and content (e.g., Introduction, Method, Results, Discussion). <i>Instructor:</i> Katie Knapp, Ph.D.
Jan 2020 – April 2020	PSYC3743: Drugs and Behaviour UNB, Fredericton, NB <i>Activities:</i> Graded midterms and final presentations; consulted with students about assignments, grades, or questions regarding course material. <i>Instructor:</i> Wendy Bourque
Jan 2018 – May 2020	PSYC4110: Honours Thesis Research Seminar & PSYC3151 Basic Research Seminar UNB, Fredericton, NB <i>Activities:</i> Answered student questions and problem-solved related to final honours thesis projects; Provided a guest-lecture on how to develop an effective curriculum vitae; Co-ordinated Honours Conference where students presented their original research to fellow students, faculty and the community; co-ordinated mock presentations prior to the event and provided students with feedback on their project and presentation. <i>Instructor:</i> Biljana Stevanovksi, Ph.D
Sept 2019 – Dec 2019	PSYC 3323: Approaches to Psychotherapy UNB, Fredericton, NB <i>Activities:</i> Graded student treatment reports and provided detailed feedback; consulted with students about assignments, grades, or questions regarding course material. <i>Instructor:</i> Scott Ronis, Ph.D., L. Psych.
Sept 2018 – Dec 2018	PSYC2603: Foundations of Memory and Cognition UNB, Fredericton, NB <i>Activities:</i> Proctored and graded student exams; consulted with students about assignments, grades, or questions regarding course material. <i>Instructor:</i> Darren Piercey, Ph.D.
Sept 2017 – Dec 2017	PSYC4053: History of Psychology

UNB, Fredericton, NB

Activities: Proctored and graded student exams; consulted with students about assignments, grades, or questions regarding course material.

Instructor: Carmen Poulin, Ph.D

Sept 2015 – May 2017

PSYC3706: Topics in Cognitive Psychology

Laurentian University, Sudbury, ON

Activities: Graded assignments; proctored and graded tests and exams; consulted with students about assignments, grades, or questions regarding course material.

Instructor: Joël Dickinson, Ph.D.

Sept 2015 – May 2017

PSYC3256: Design and Analysis

Laurentian University, Sudbury, ON

Activities: Assisted students in data analyses for their individual research papers; Graded research papers; proctored and graded tests and exams; consulted with students about assignments, grades, or questions regarding course material.

Instructor: Joël Dickinson, Ph.D.

Sept 2015 – April 2016

PSYC1105: Introduction to Psychology

Laurentian University, Sudbury, ON

Activities: Graded assignments and tests; consulted with students about assignments, grades, or questions regarding course material

Instructor: Cynthia Whissell, Ph.D

RESEARCH ACTIVITIES

RESEARCH INTERESTS

The cognitive experience of trait anxiety; cognitive psychology (language, attention, and working memory)

RESEARCH EXPERIENCE

2016-2017

Lab Manager

Cognitive Health Research Laboratory, Laurentian University, Sudbury, ON

Activities: Coordinated lab meetings; supervised student research including participant recruitment, data collection, equipment training (e.g., EEG), writing manuscripts and preparing conference presentations.

Supervisor: Joël Dickinson, Ph.D.

- May 2016- September 2016 **Assistant for PhD Student Dissertation in Speech Language Pathology**
 Laurentian University, Sudbury, ON
Activities: Responsible for data management and entry, running non-parametric tests in SPSS and summarizing results.
Supervisor: Leanne Genier-Bedard, Ph.D.
- May 2016 – July 2016 **Assistant for PhD Student Dissertation in Psychology**
 Laurentian University, Sudbury, ON
Activities: Responsible for general editing of written work, organizing ideas, reading background literature and integrating this information into my editing, and working on results sections (e.g., creating tables).
Supervisor: Julie Shilhan, Ph.D.
- 2015 – 2017 **Research Assistant**
 Cognitive Health Research Laboratory, Laurentian University, Sudbury, ON
Activities: Assisted in preparing various manuscripts for publication
Topics: Emotional facial recognition; Confusion between anger and disgust; Discriminating fear and surprise; English versus French versions of the WISC
Supervisors: Annie Roy-Charland, Ph.D., L. Psych
 Joël Dickinson, Ph.D.
- 2012 – 2015 **Research Assistant**
 Sydney, NS
 Language and Reading Lab, Cape Breton University,
Activities: Data collection, scoring, and data management of large-scale language and reading development research in school-aged children using standardized measures such as sub-tests of the Kaufman Brief Intelligence Test (KBIT-2), the Clinical Evaluation of Language Functioning (CELF), the Woodcock Reading Mastery Test-Revised, and the Comprehensive Test of Phonological Processing (CTOPP). Responsible for recruitment, data collection, and data analysis in a study using Event-Related Potentials with university students. Responsible for study design, recruitment, data collection and data analysis for a study using Eye tracking with school-aged children.
Supervisor: Erin Robertson, Ph.D.

PUBLICATIONS

- Ferguson, R., Roy-Charland, A., Rowe, S., Perron, M., & **Gallant, J.** (2021, July 22). Examining featural processing of emotional facial expressions: Is trait anxiety a factor? *Canadian Journal of Behavioural Science*. Advance Online Publication.
- Robertson, E.K., & **Gallant, J.E.** (2019). Eye tracking reveals subtle spoken sentence comprehension problems in children with dyslexia. *Lingua*, 228.
*Selected as Editor's choice, October 2019
- Dudar, K., Ghaderi, G., **Gallant, J.**, Dickinson, J., Abourbih, J., & Briggs, M. (2018). Queering the medical curriculum: How to design, develop, deliver and assess learning outcomes relevant to LGBT health for health care professionals. *MedEdPublish*, 7(1), 48-55.

PRESENTATIONS

- Gallant, J.**, & Stevanovski, B. (2019, November). Poster presented at the 60th annual meeting of the Psychonomics Society. Montreal, Quebec.
- Dickinson, J., Hendel, E., **Gallant, J.** (2017). When is a schematic violation not a schema violation? Poster presented at the Psychonomic Society Annual Meeting, 2017, Vancouver, British Columbia.
- Dickinson, J., Laliberte, A., **Gallant, J.**, Hendel, E., Malette, J., & Desrosiers, C. (2017). Fluency and schema congruence impact on attribute ratings and reading times. Poster presented at the Canadian Society for Brain, Behaviour and Cognitive Science, Regina, Saskatchewan.
- Gallant, J.**, Hendel, E., Malette, J., Vaillancourt, D., & Dickinson, J. (2017). The mechanic dropped her wrench: The influence of manipulating fluency on reading speed and attribute ratings during schema violations. Poster presented at the Canadian Society for Brain, Behaviour and Cognitive Science, Regina, Saskatchewan.
- Gallant, J.**, Pakula, D., Malette, J., Kennedy, H., & Dickinson, J. (2017). Eye tracking in search of relationships between brand visibility, brand recognition and brand recall while viewing Netflix. Poster presented at the Canadian Society for Brain, Behaviour and Cognitive Science, Regina, Saskatchewan.
- Gallant, J.**, Dickinson, J., Roy-Charland, A., Chamberland, J., Perron, M., & Poulin, J. (2017). The role of attentional resources in facial expression processing among individuals with anxiety: An Event-related potential study. Poster presented at the Canadian Society for Brain, Behaviour and Cognitive Science, Regina, Saskatchewan.
- Gallant, J.**, Ferguson, R., & Roy-Charland, A. (2017). The mediating role of emotion dysregulation on the relationship between socially-prescribed perfectionism and anxiety. Poster presented at the Anxiety and Depression Association of America Conference, 2017, San Francisco, California.
- Dickinson, J., Chamberland, J.A., Smith, P., Streich, B., **Gallant, J.**, & Graham, M. (November 2016). The Impact of Perceptual Fluency on the Gender and Sexuality IAT Effect: An ERP Investigation. Poster presentation at The Psychonomic Society Annual Meeting, 2016, Boston, Massachusetts.

- Robertson, E.K. & **Gallant, J.E.** (2016). Spoken sentence comprehension in children with dyslexia: an eyetracking study. Poster presented at the 23rd Annual Meeting of the Society for the Scientific Study of Reading, Porto, Portugal.
- North, B., **Gallant, J.**, Chamberland, J., LaForge, C., Ferguson, R., Graham, M., Newton, C., & Dickinson, J. (June 2016). *Does positive equal negative? A test of the attentional bias in high trait anxiety.* Poster presentation at Canadian Society for Brain, Behavior & Cognitive Science, Ottawa, Ontario.
- Gallant, J.** (June 2015). *The effect of the local noun on subject-verb agreement processing in adults.* Oral presentation at Cape Breton University Summer Lecture Series.
- Gallant, J.** & Robertson, E. (May 2015). *Spoken sentence comprehension in children with dyslexia: An eyetracking study.* Poster presented at the Atlantic Conference on Reading and Language Acquisition, 2015, Halifax.
- Gallant, J.** & Robertson, E. (March 2015). *Spoken sentence comprehension in children with typical and atypical reading development: An eyetracking study.* Oral presentation at Cape Breton University Research Week.
- Robertson, E.K., MacDonald, K. J., **Gallant, J.E.**, & Kozera, K.N. (November 2013). *Does the local noun influence neural processing of subject-verb number agreement violations? An Event-Related Potential study.* Poster presented at The Psychonomic Society Annual Meeting, 2013, Toronto, Ontario.
- Gallant, J.** & Robertson, E. (August 2013). *Measuring sentence processing in adults with event-related potentials.* Oral presentation at Cape Breton University Summer Lecture Series.

RESEARCH SUPERVISION EXPERIENCE

Sept 2016 – May 2017

Co-Supervision of Honours Theses

Laurentian University, Sudbury, ON

Activities: Provided co-supervision to three undergraduate students completing their honours theses in the Cognitive Health Research Laboratory; Assisted with development of research questions, methods, statistical analysis, and manuscript revisions.

Titles:

- 1) Eyetracking in search of relationships between brand visibility, recall and recognition while viewing a Netflix program
- 2) The mechanic dropped her wrench: the impact of manipulating fluency on reading speed and attribute ratings during schema violations
- 3) Fluency and schema congruence's impact on attribute ratings and response times

Supervisor: Joël Dickinson, Ph.D.

Sept 2016 – May 2017

Co-supervision of Undergraduate Research

Activities: Provided co-supervision to five undergraduate students completing their Basic Research practica in the

Cognitive Health Research Laboratory; Assisted with development of research questions, methods, and statistical analysis; edited written work and provided feedback on conference presentations.

Supervisor: Joël Dickinson, Ph.D.

REFERENCES

Dr. Jennifer Ducharme, Ph. D., C. Psych

Clinical supervisor

Shared Health, Winnipeg, M.B.

Dr. Lauren Chance, Ph. D., C. Psych

Clinical supervisor

Shared Health, Winnipeg, M.B.

Dr. Hilary Cartwright, Ph.D., L. Psych

Clinical supervisor

Hilary Cartwright & Associates, Fredericton, N.B.

Amy Otteson, MA., L. Psych

Clinical supervisor

Horizon Health, Fredericton, N.B.

Dr. Biljana Stevanovski, Ph.D.

Research supervisor

University of New Brunswick, Fredericton, N.B.