Effects of Stress on Cognitive Task Performance: the Role of Working Memory Capacity

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Summary

Major formulations of stress are presented (Cannon, 1932; Selye, 1951-1956) both to clarify the nature of what has proved to be a familiar but vague construct, and also to provide background to the theoretical context (see Koolhaas et al., 2013, for a review). In Chapter 1, the interplay between stress and Working Memory (WM) is introduced where WM: (a) represents a 'domain-free' or 'domain-general' ability to control attention, (b) is separable from short-term memory (STM), and (c) is an important component of the cognitive architecture most affected by stress (Schoofs, Preuss, & Wolf, 2008; and Wolf & Smeets, 2009).

Current immediate-memory theories (e.g., cognitive interference theories; see Eysenck, Derakshan, Santos, & Calvo, 2007) are reviewed in the following chapters, chapters 2 and 3, which represent a robust approach to stress and cognition. The main focus is on anxiety—a form of stress (Mauricio, 2009)—within general populations rather than within anxious ones, and there is an emphasis on individual difference characteristics in anxiety as a disposition or trait, typically assessed by self-report scales of anxiety such as Spielberger's State-Trait Anxiety Inventory.

Two hypotheses are developed and tested using the results obtained from two separate studies, Study 1 (Chapter 4) using traditional paper and pencil measures of anxiety, and Study 2 (Chapter 5) using more physiological measures, including galvanic skin conductance and heart rate variance. The first hypothesis examined the impact both of domain-general and domain-specific individual difference characteristics on performance in a complex aviation task environment (cf. Sohn & Doane, 2003). Results indicated that increase in WM capacity (WMc, i.e., domain-general attention) reduces the role of domain-specific skill variables (or incoming ability e.g., experience and training). The second hypothesis tested an interaction hypothesis to determine whether a combination of high WMc and high anxiety would predict variance in a complex aviation task environment. A criterion measure of task performance

('flight error') was related to the predictor measures, where flight error was reduced in high anxious individuals with high WMc.

A second Study sought to further assess the interplay between the study variables, assessing whether the results of Study 1 could be replicated in a more stressful context. A stimulation shock box, together with the threat of shock, was used to ensure that "lasting affect was actually elicited" (Shackman et al., 2006, p. 42). The same hypotheses were tested again and generally confirmed the findings of Study 1, except this time in what was evidently a stressful context. Physiological measures of galvanic skin conductance and heart rate variance were also captured and confirmed the presence of the target emotion. Overall, the results suggest that although threat-based cognition (i.e., anxiety) is often associated with some underlying restriction in the functional capacity of WM, it may also, given particular conditions, be associated with recruitment of attentional control, depending on the processing resources available. More generally, the present thesis accords with theories of attention for complex cognitive tasks and is consistent with a recent review by Eysenck et al. (2007, but see also Eysenck & Derakshan, 2011).

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements) nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

Acknowledgements

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Ethics Approval

Ethical approval for this research was granted by Macquarie University Human Ethics Committee on the 14th October 2014, ethics approval reference: 5201200229.

Abstract

The Processing Efficiency Theory (PET) and the more recent Attentional Control Theory (ACT) (called "cognitive interference theories" by some researchers) suggest that the effects of threat-based cognitions on cognitive processing are concentrated on the central executive of Baddeley's (1986, 2001) working memory (WM) system. These theories assume that negative emotions, particularly anxiety, impair the efficiency (and effectiveness) of three executive functions: the inhibition, shifting, and updating functions. However, there may be conditions (e.g., domain-general or domain-specific conditions) in which that assumption is not applicable (Eysenck, Derakshan, Santos, & Calvo, 2007).

Two studies were designed to investigate the impact both of domain-general and of domain-specific individual difference characteristics on performance in a complex aviation task environment. Two specific aims were pursued. These were, first, to test the effect of administration method on the predictive utility of a commonly used updating task, the WM task, and second, to examine the locus of the varied ability to satisfy WM demands of this task. With respect the second aim, two specific sub-questions were asked:

(a) To what extent are individual differences in cognitive task performance domain general (WM as a fixed capacity; WMc) or domain-specific (WM as an acquired skill); and

(b) To what extent are individual differences in WM (as a fixed capacity) useful for covering or limiting the stress response? That is, could a combination of high WMc and high anxiety interact to explain variance in cognitive task performance, namely, performance in a complex aviation task environment.

Using a psychometric approach, the experimental manipulation of threat-based cognitions—both in studies 1 and 2—cast new light on the probable architecture of the human WM system, and, to a lesser extent, the specific attentional processes captured by updating tasks (so-called tests of WM). Seventy four students aged between 18 and 29 years participated in the first study, which measured self-report levels of state anxiety, working memory and

cognitive task performance (indexed by average within-subject error for rate of descent, hereinafter referred to as “flight error”). As hypothesised, although domain-specific skills were correlated with flight error, they did not account (or add) any unique variance beyond that which could be accounted for by domain-general attention. In addition, higher levels of state anxiety were also associated with reduced flight error, a novel finding that was observed among participants with higher, but not lower, domain-general attention (i.e., WMc). The findings from each of these tests suggest that WM depends on domain-general processing and control systems, and that updating tasks capture individual differences in the ability to combine maintenance and processing demands in a manner that limits loss of information. These results are therefore broadly consistent with Attentional Control Theory (ACT) and demonstrate that high-anxious individuals may, given sufficient resources, overcome the stress response.

A second study (Study 2) was carried out as a follow-up to help confirm the above results. The initial study was therefore repeated, except this time, the threat of shock was used to ensure that the intended “affect [was] actually elicited (Shackman et al., 2006, p. 42). Again the results generally confirmed the findings of Study 1, with self and physiological measures confirming the “presence of the intended emotion” (p. 42). Together with the result of Study 1, these results suggest that although threat-based cognitions (i.e., anxiety) are often associated with some underlying restriction in the functional capacity of WM, it may also, given particular conditions, be associated with recruitment of attentional control, depending on the processing resources available. These results are discussed with specific reference to the self-help and coping literature and the development and influence in the wider literature of the attentional control theory (Eysenck et al., 2007). In addition, the extensive research (including several cognitive perceptual studies) of direct relevance to ACT are discussed, and suggestions are made for maximising the value of future cognitive perceptual stress research.

1 Chapter One: The Stress Concept

1.1 Introduction

The stress concept has been the subject of increased debate ever since its first use by Walter Cannon (1914) in the early 20th Century. Mental stress (negative mood states), in particular, assumed an increasing relevance in the self-help and general stress literature as plausible effects, at both the adaptive and maladaptive level, began to be realised (Huttunen, Keränen, Väyrynen, Pääkkönen, & Leino, 2011). Yet for all this interest and pursuit, there was still little evidence on which to base credible 'self-help' decisions concerning how anxious individuals would approach stressful situations, (i.e., what strategies are best when processing becomes inefficient), nor was there cogent or compelling evidence that there was any 'value' to anxious individuals that did employ any kind of compensatory strategy (Eysenck et al., 2007).

Eysenck and Derakshan (2011) stated that, despite theoretical advances in the stress literature, the precise circumstances in which deficient recruitment of processing resources may occur was not known, the particular conditions in which meaningful (but inefficient) recruitment of processing resources may occur was not known, and that evidence for the use of compensatory strategies and their 'value' was also lacking. It seems clear from these remarks that there may be a distinction to be had between *efficiency* and *effectiveness* (i.e., task-quality), with efficiency decreasing as more resources are used to maintain a standard level of performance.

This study attempts to address some of the above deficiencies by investigating two presumably germane issues to the understanding of cognitive processing. First, to what extent are individual differences in cognitive task performance *domain-general* or *domain-specific*? Second, to what extent are individual differences in WM (as a fixed capacity) useful for covering or limiting the stress response? If high anxious individuals have auxiliary resources, then placing a load on the *mental workplace* should reduce efficiency but not the effectiveness of cognitive task performance. Although findings are often difficult to interpret, the present study, via the manipulation of stress, should give way to a more theory-based account that provides a web of thinking and insights to help guide future research.

1.2 What is Stress?

It is a question that has beguiled and confused both publicists and students of emotion for the past centenary (Cannon, 1932; Caplan, 1964; Hobfoll, 1989; and Selye, 1950, 1951-1956). The term itself is loosely borrowed from the field of physics and holds a precise meaning: humans, it is thought, are in some way analogous to the structure of metal, capable of withstanding only so much pressure. Although somewhat inexact, similar formulations have since followed. Robert Hooke, for example, used the term ‘stress’ to denote the exerted pressure of a load to an area of a given material, and ‘strain’ to denote the subsequent loading strain (i.e., ‘deformation’) in that material, albeit in an engineering context (Cooper & Dewe, 2008, but see also Le Fevre, 2007).

To Walter Cannon (1932) belongs the credit of first applying the stress concept to humans in these terms. Cannon was principally concerned with steady states of the body and the regulation of the body to challenges such as hypoxia (lack of oxygen) and the effects of cold. He pointed out that natural adjustments in the body were themselves essential—even adaptive—in preparing the body for a flight or fight reaction:

> *“These changes in the body are, each one of them, directly serviceable in making the organism more efficient in the struggle which fear or rage or pain may involve; for fear and rage are organic preparations for action, and pain is the most powerful known stimulus to supreme exertion.”* (Cannon, 1914, p. 372).

Cannon further went on to surmise that human beings survive by maintaining their own stability or *set point*. The idea that the body is regulated by natural powers, by a vis medicatrix naturae (literally 'the healing power of nature'), insinuates the presence of disposable agencies ready to operate within narrow ranges when steady states of the body are upset. Challenges in this sense are thought to excite reactions in the body, or affect it directly, and so set the occasion for a natural adjustment (or readjustment)—called, homeostasis (Cannon, 1929).

In addition to their regulatory function, Cannon (1929) also recognised that the natural adjustments of the body were themselves non-specific; that is, the open system of the body would react to all internal disturbances in a similar fashion whether such a natural adjustment was immediately appropriate or not. This, in conjunction with the referenced citation, might be the first instance or indication that the perception of stress may be an important determinant of what is necessarily stressful (Fevre, 2007). Indeed, it was this very notion that spurred theorists into two rather divergent schools of thought—an endogenous view of stress versus an exogenous view of stress.

1.2.1 The Cannon-Selye Tradition: Response-based (endogenous) View

Cannon's original emphasis on 'stress as a physiological response' was carried on and developed by Hans Selye (1950, 1951-1956). In his early work as a medical student, Selye observed that patients with dissimilar illnesses shared a basic set of signs and symptoms (e.g., the heart may beat more rapidly and strongly) and that these signs and symptoms were essentially an orchestrated defense, designed principally to protect the body.

Selye felt that there was a common 'natural adjustment' to outside agencies following the sequence of an initial alarm stage—analogous to Cannon's fight or flight reaction, a resistance stage, and a stage of exhaustion. If the capacity of the organism to adapt was overwhelmed, or the body's reserves were depleted, then chronic disease or death may result. He called this the General Adaptation Syndrome (Selye, 1956, 1964).

Despite the headway that the Cannon-Selye tradition has made, it can be criticised on two counts (Day, 2005; and Romero, Dickens, & Cyr, 2009). First, several researchers have criticised the ambiguity and circularity of the definition of stress in terms of a disharmony or threatened homeostasis. Virtually all activities in the body are concerned with self-regulatory arrangements, and thus the definition of stress as a threat to the body "*is almost meaningless*" (Koolhaas et al., 2011, p. 1292). Second, and related to the first point, the idea that many physiological and psychological reactions to stress have a "*common denominator*" (Selye, 1976, p.5) or common reaction can be challenged by a wealth of data (Stokes & Kite, 2001). How people adapt in the face of unfavorable influences or to threat-based cognitions can be seen as a function their constitution and motivational state (Koolhaas et al., 2011).

1.2.2 The Stimulus Definition of Stress: Stimulus-based (exogenous) View

A less well-established view of stress centers on the stressor, or that which is likely to *cause* stress (Hobfoll, 1989). This thinking loosely borrows from the field of psychiatry and follows the work of Caplan (1964) and Lindemann (1944). In particular, their work emphasised that threat-based reactions were not necessarily the product of bodily processes, as some biomedical theorists would have it, but rather the product of certain conditions, such as confrontation with an especially stressful stimuli.

An exogenous view of stress is therefore a good starting point because it not only outlines the agencies that are likely to cause threat-based cognitions, but also sets an anchor point by which the nature of stress can be further categorised: *acute, time-limited stressors* such as the anticipation of a syringe or needle. Even still, this viewpoint has been criticised because it fails to consider individual differences in a person's appraisal of what is necessarily stressful. Indeed, even if this viewpoint were accepted, it is clear that the stimulus—the stressor in the strictest sense—is only one facet of the stress concept (see Hobfoll, 1989). How then should stress be defined?

1.3 Koolhaas et al. (2011): A Critical Evaluation of the Stress Concept

In a critical evaluation of the stress concept, Koolhaas et al. (2011) stated that the "conventional usage of the stress concept *bears* considerable *problems*" (p. 1291, emphasis added).

The foregoing sentiment was in part the result of a workshop held by Eberhard Fuchs and Jaap Koolhaas in 2011, Göttingen, Germany. In the workshop, it was discussed that there was a general lack of consistency across the theoretical models of stress and that a precise definition of 'stress' was also lacking. Specifically, the group felt it necessary to revitalise the view that stress was a cognitive perception: stress, it was felt, was an appraisal or perception of the predictability and/or controllability of a given condition. In this way, stress was neither the stimulus nor the stress response, but rather the perception of these factors.

The terms 'predictability' and 'controllability' are therefore central to an understanding of what has come to be known as stress. This perspective follows loosely from the work of Weiss (1972), who illustrated that it was *not* the onerous nature of stimuli that incites various forms of pathology but rather the extent to which stimuli are themselves predictable or controllable. What then is the difference between these terms if they are not fully independent?

First, to the notion of what is predictable. Given the natural regulatory capacity of an organism is to prepare in anticipation of an aversive stimuli, uncontrollability, or lack therefore, should be characterised by the "*absence of an anticipatory response*" (Koolhaas et al., 2011, p. 1292). Along these lines, de Boer et al. (1990) found that rats showed a strong anticipatory corticosterone response to the stress of food availability. Hence it may be the absence of an anticipatory response rather than the natural adaptive capacity of a living being—the rat, in the case of de Boer et al.—that dissociates a predictable from unpredictable event (Ferrari et al., 2003).

As to the notion of what is controllable, a stressor may be further distinguished by the recovery of the physiological response. The experiments of de Boer et al. (1990) showed that elevated levels of corticosterone took a slow downward slope to baseline for rats in a non-reward (‘stress’) condition, whereas for rats in a reward condition, corticosterone levels rapidly declined. Hence, in this context, it may be the reduced recovery of the neuroendocrine reaction (or the reduced recovery to baseline) that dissociates what is controllable from uncontrollable (Fish et al., 2005; see figure 1.1).

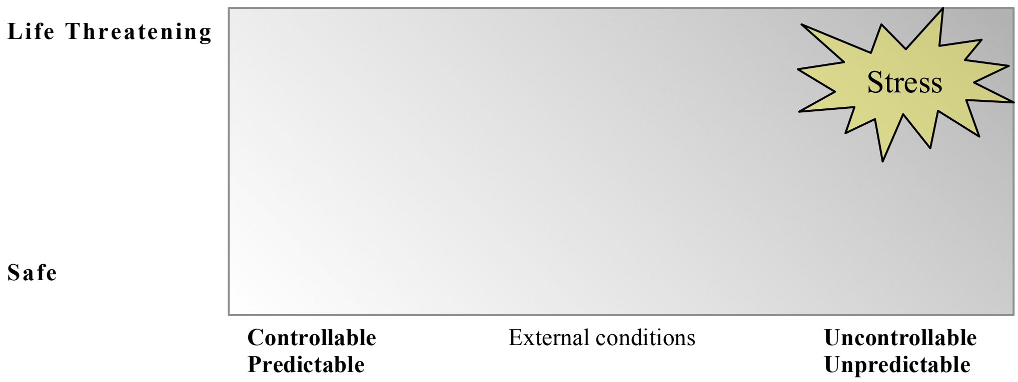


Figure 1.1 Koolhaas et al.'s (2011) Original Drawing of Stress. Figure depicts the graded relationship between degree of uncontrollability/unpredictability and the life-threatening nature of the stimulus. Thus the term "stress" should be used to denote conditions and that present in right top corner of the graph. By comparison, the lower left part of the Y-axis depicts the realm of *normal physiological reactions that are mandatory to support behaviour.*

Apart from the qualitative definition of the stress concept, there is the question of intensity or the quantitative nature of the stressor. At an individual level, ones perception of stress, though far from idiographic, may vary from safe (i.e., mild) to life threatening. For example, only about 20-30% of individual’s who have a distressing life encounter will themselves suffer from post-traumatic stress disorder (PTSD; Breslau, 2001). It follows even from a cursory inspection of the y-axis shown in Figure 1.1 that cognitive processing may further influence the severity of a stressor. Indeed, those who experience an event as life threatening, like the 20-30% of PTSD suffers, are more accurately depicted in the top right corner of Figure 1.1.

1.3.1 Stress Summary and Definition Used in this Thesis

It may well be that threat-based cognitions are an inescapable and ever present reality, yet as eustress (positive/beneficial stress, Seyle, 1956; 1987), it also appears to harbor the potential for a positive interpretation or reaction. It seems, therefore, essential that modern psychology attempt to further understand the stress concept. For example, is it possible to ameliorate the aversive effects of stress? Under what circumstances may highly stressed individual's recruit processing resources, albeit inefficiently? The recent paper by Koolhass et al. (2011), which has begun to revitalise the view of stress as a cognitive perception, may lead to new appreciations of the neuroendocrine and physiological response as basis from which to characterise the stress concept. In the meantime, the stress concept remains both broad and amorphous (Staal, 2004).

Stress, it would seem, is part of our daily human existence; present in the trader watching the stock market; in the small business owner fearing bankruptcy; in the daughter helplessly watching her father's slow, increasing impairment with learning and memory (Alzheimer's disease); and in the man with macular degeneration who's eyes grow dimmer each day. Indeed, it follows that a discussion of stress and the problems which it poses—especially on memory—should be properly prefaced by an acceptable definition, a definition the terms of which are neither too broad nor too narrow. For the sake of terminological consistency, the paper adopts the stress definition proposed by Koolhass et al. (2011) "…a cognitive perception of uncontrollability and/or unpredictability that is expressed in a physiological and behavioural response" (p.1292).

1.4 Stress and Memory

Previous research has shown that the effects of negative mood states (e.g., threat of shock or cold pressure stress) on cognitive processes are either impaired (Schoofs, Preuss, & Wolf, 2008; and Wolf & Smeets, 2009) improved or not affected (Duncko, Johnson, Merikangas, & Grillion, 2009; and Vedhara, Hyde, Gilchrist, Tytherleigh, & Plummer, 2000). Additionally, there is also evidence to show that threat-based cognitions not only affect declarative memory (the ability to recall information) and its associated brain regions (e.g., hippocampus and amyglada; Roozendaal, McEwen & Chattarji, 2009), but also involves cognitive interference by preempting the limited attentional resources—*processing* and *storage* capacity—of WM (Wolf & Smeets, 2009). While the cognitive architecture behind these effects remains poorly understood, it seems likely that the main effects are on the *central executive*: a domain-free or domain-general function of WM (Eysenck et al., 2007; but see also Table 1). [1]

Table 1.1
Sample of Research Studies Showing the Effects of Stress on Working Memory

Source	**Stress Manipulation**	**Outcome**	**Setting**
Vasmatzidis, Schlegel, & Hancock (2002)	Heat	Visual Tracking and Auditory Discrimination Degraded	Laboratory
Lopez, Previc, Fischer, DaLuz, Workman, Ercoline, Evans, Dillon, Engle, & Heitz, unpublished data, as cited by Engle (2010)	Sleep Deprivation and Fatigue	Reductions in Working Memory Capacity and Flight Performance	Laboratory/Flight Simulation
Wolf & Smeets, (2009)	Cold Pressure	Learning, Working Memory Impaired	Laboratory
Lieberman, Bathalon, Falcon, Georgelis, Morgan, Niro, & Tharion (2002)	Military Combat	Learning, Working Memory, and Logical Reasoning Degraded	Simulation

[1] In the present research, we discuss memory as working memory, and unless otherwise specified in the text, the reader should consider general references to memory as references to working memory.

Beilock, Rydell, & McConnell (2007)	Stereotype Threat	Modular Arithmetic and Working Memory Decrements	Laboratory
Keinan (1989)	Electrical Stimulation	Decision Scanning Decrements	Laboratory
Croizet, Despres, Gauzins, Huguet, Leyens, & Meot (2004)	Stereotype Threat	Decrements in the Ability to Draw Meaning From Ambiguity	Laboratory
Schoofs, Preuß, Wolf (2008)	Cold Pressure and Psychosocial Stress	Significant Working Memory Impairments (Efficiency and Effectiveness)	Laboratory
Van Galen & Van Huygevoort (2000)	Time Pressure and Increases in Workload	Visual Tracking Degraded	Laboratory

1.5 What is Working Memory?

The term *working memory* has become an almost universal phrase in the modern parlance of cognitive psychology (Jarrold & Towse, 2006).

Some researchers have, for example, used the WM term in a *general* sense as meditating most of our conscious interactions (Conway, Jarrold, Kane, Miyake, & Towse, 2007), others have described it at a more practical level in terms of its size and capacity, and still others have used the term in a more literal sense—as a cognitive function—responsible for holding immediate-information in an easily retrievable state (Repovs & Baddeley, 2006). These descriptions, however, can be contrasted with more general theories of immediate memory, which have stressed the *functional importance* of system could store a limited amount of information in the face of ongoing processing and/or distraction (Baddeley & Hitch, 1974, 2000).

This shift toward a more functional view of WM reflects the purported role of WMc in many real-world activities (Ricker, AuBuchen, & Cowan, 2010) and global models of cognition (Conway et al., 2005). Indeed, it was this very shift toward a more functional view of immediate-memory that, matched by the adoption of the '*working memory'* term, marked the onset of an era of research into the probable architecture (or structure) of the human WM system and, moreover, its fruitful role in a range of highly complex cognitive behaviours (Jarrold & Towse, 2006; see Figure 1.2a–c).

(a) Atkinson and Shiffrin (1968) Model

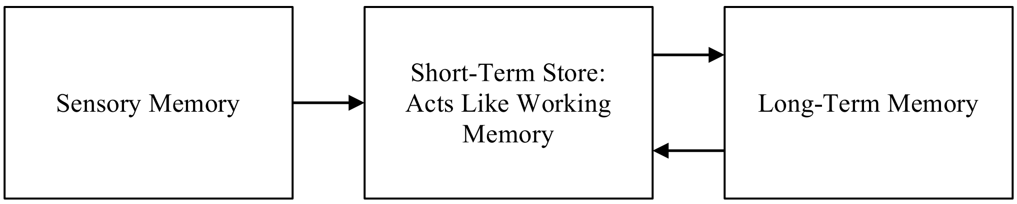
One of the more dominant views of WM in the late 1960's was the so-called modal model of short-term memory (STM; Atkinson and Shiffrin, 1968; cf. Hebb, 1949). Some of the most compelling evidence for this modal model came from the study of amnesic patients and patients with grossly impaired STM. For example, when asked to perform tasks that were assumed to engage STM, those patients suffering from amnesia appeared unimpaired, whereas those patients with gross deficits to STM showed normal long-term learning. These findings, together with evidence from the study of normal subjects, appeared to support at least two forms of memory—a STM store, which served as a *working memory* store, and a more durable LTM store (see Figure 1.2a, but see also Baddeley, 1992).

(b) Baddeley (1986, 2001) Model

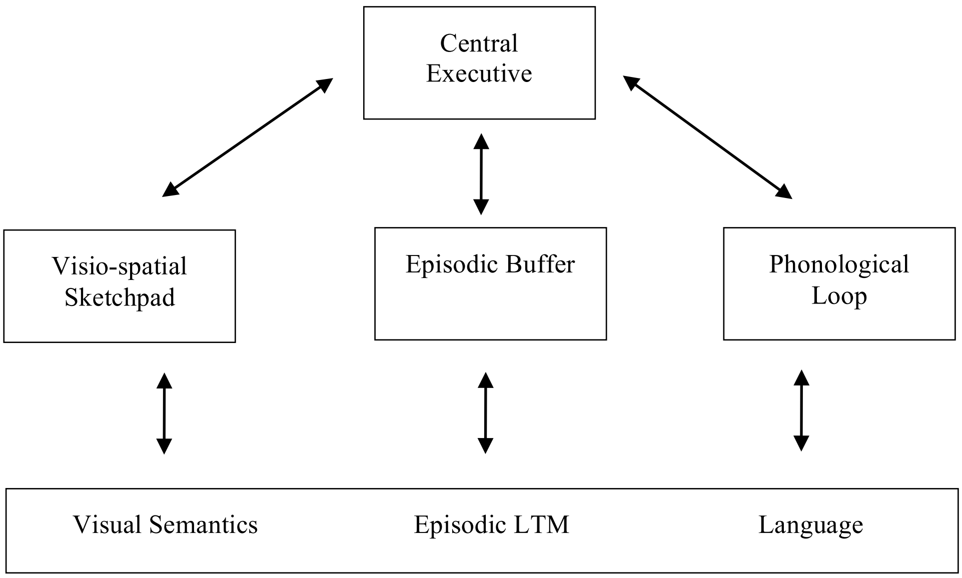
By the mid 1970's it was apparent that the two-component view of WM had several shortcomings. If the STM store in Atkinson and Shiffrin's model served as a WM store, then patients with specific STM deficits should show little to no capacity for everyday cognitive activities, yet this was not the case: in fact, one was a proficient secretary, another a driver of a taxi, while a third was the owner and manager of a small business (as cited in Baddeley, 2003).

Taken together, these results encouraged the denunciation of the idea of a single unitary system. In 1986, Baddeley instead proposed a multicomponent tripartite system (shown in Figure 1.2(b)), which comprised two independent slave systems for the storage of verbal-speech based and visuo-spatial information, and a *central executive* or domain-general supervisory mechanism for the allocation of attention (Baddeley, 1986; 2001). Thus, the model outlined in Figure 1.2(b) divided the unitary STM store shown in Figure 1.2(a) into three separable components, which, while partially interdependent, were assumed to work together as part of a unified system that served the function of facilitating the performance of higher-order cognition.

(a) Atkinson and Shiffrin (1968)



(b) Baddeley (1986, 2001)



(c) Norman and Shallice (1986)

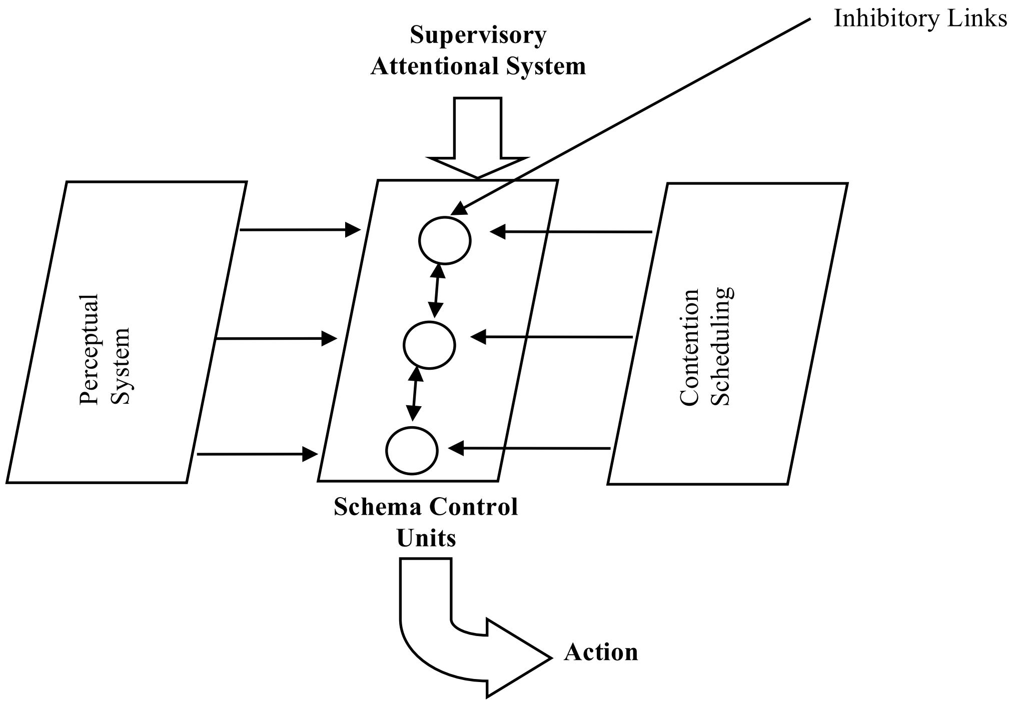


Figure 1.2. Three Illustrations of Working Memory as Conceptualised by: (a) Atkinson and Shiffrin (1968); (b) Baddeley (1986, 2001); and (c) Norman and Shallice (1986). A common feature of these WM models is the presence of some central faculty, or 'control unit' that controls types and levels of processing, disposing commands executed by peripheral or subordinate processes (e.g., Kane & Engle, 2003). In the above models, researchers have typically grouped these functions; for example, Baddeley (1986, 2001) attributes them to cognitive processing of the central executive in Figure 1.2(b), and Norman and Shallace (1986) attribute them to their SAS system in Figure 1.2(c).

As to the specific function of the central executive, Baddeley asserted it as the "most important but least understood component of WM" (2003, p. 835). In his original model, it was almost certainly unspecified, being treated as a convenient homunculus—a sort of assertive 'little man' that in some enigmatic way manages all the decisions and tasks not currently explained by the model. In recent years, however, Baddeley defined it not as "the collective area of residual ignorance" (1986, p.225), but as an "attentional control system" that includes distinguishable processes, including, for example, the active maintenance and monitoring of incoming information (2001, p.2).

(c) Norman and Shallice (1986) Model

In 1986, the first major attempt to advance the concept of the central faculty, i.e., the central executive, came with the proposal to adopt the immediate-memory framework of Norman and Shallice. According to Norman et al., human action was controlled principally by two qualitatively distinct processes (or schemata): the first, contention scheduling, was relatively automatic and based on predictable or routine events, whereas the second, the Supervisory Attentional System (SAS; an intervening model), was based on the correcting of non-routine events. Thus, where Baddeley (1986, 2001) attributed the controlled processes of attention to the central executive, Norman and Shallice attributed them foremost to the SAS (See Figure 1.2 (c)).

1.6 Working Memory Summary and the Psychometric Approach

The theoretical concept of WM proposes that a dedicated system is necessary for the concurrent storage and manipulation of information and that this immediate-memory system underlies human cognition. Investigations into WM have shed new light on the probable architecture of the WM system, and perhaps, to a lesser extent, the specific resources ("executive functions") that underlie cognitive task performance (Jarrold & Towse, 2006). However, general immediate-memory research has also had a rather important role in the development of WM theories. In particular, psychometric approaches to the study of WM have been informative in at least two areas. These are, first, the importance of memory span tasks (so-called tests of WM or updating tasks) to predict practically and theoretically important cognitive tasks, such as learning and reasoning, and, second, the importance and extent that performance on such tasks rely on a domain-free or 'domain-general' attention.

This psychometric approach, albeit correlational, has an advantage in that it can test what is arguably the most vital feature of the immediate-memory system, the central executive, and can furthermore work on academic issues, such as the impact of certain laboratory conditions on cognitive processing (psychological, psychosocial and physiological stress). How, then, do researchers explain the covariation of WM and cognitive task performance?

1.7 Individual Differences in Working Memory

It is helpful to consider the foregoing question in the light of the psychometric approach, particularly as it applies to theories of immediate-memory. The essence of the psychometric approach, for example, focuses on the extent to which performance on updating tasks (i.e., tests of WM) can predict individual differences on practically and theoretically important cognitive skills, such as the ability to read (Baddeley, 1992) and/or solve problems.

One influential study in this paradigm of research is Daneman and Carpenter's (1980) study into adults' comprehension ability. In their study, subjects were presented with sets of unrelated sentences that they had to read and verify as being true or false, with the added constraint that final words of each sentence had to be stored for subsequent recall. They called this the reading span task or "*Rspan"* (a complex WMc span task, sometimes referred to as an updating task; see Table 1.2).

Table 1.2
Commonly Used Processes in Reading Span Task by Daneman and Carpenter (1980)

Mammals are vertebrates that give birth to live young
March is the first month in the year that has thirty-one days
You can trace the languages English and German back to the same roots
The Supreme Court of the United States has eleven justices
Process: true/false judgement
Storage: (young; days; roots; and Justices)

Note: The requirement to both process and store information is thought to provide a closer approximation to everyday complex cognitive tasks than tests of STM which do not involve the additional processing demand of the secondary task.

Daneman and Carpenter (1980) found that performance on this task was more strongly correlated with reading ability than with classic tests of STM. They argued that this was because STM tests do not sufficiently tax the executive functions of the WM immediate-memory system. Indeed, researchers have previously tried to find robust correlations between STM performance and global tests of reading ability; however, unless their samples included adult dependent children, or, indeed, very young children, the correlations that emerged were marginal at best (i.e., weak, 0.28; for a review, see Daneman & Merikle, 1996).

Daneman and Carpenter (1980) argued that weak correlations might reflect the general adequacy (or rather inadequacy) of STM theory. STM tasks, such as the digit span and word span, measure only the ability to store and maintain information, but do not obviously require any manipulation or processing of information, at least in any substantial way. Such measures therefore point to the inadequacy of the classical 'slot' conception of memory, which treats STM as passive storage buffer (see, for example, Jarrold & Towse, 2006).

On the other hand, WM tasks such as the *R*span involve more online or active processing of information. According to Daneman and Carpenter (1980), people differ in their functional capacity to process and store information. Hence the less efficient processes of a poor reader, for instance, are effectively similar—or functionally equivalent—to a smaller capacity store. Such inefficiencies therefore imply that poor readers may be disadvantaged in that they have to contend with greater computational constraints on their cognitive workspace, namely their WM.

Based on this argumentation, Daneman and Carpenter (1980) assert that reading was an essential feature of the *R*span, and that in order to predict reading ability, the *R*span must make use of reading strategies: people, by their logic, had large reading spans because they were essentially good readers. Turner and Engle (1989), however, argued differently: people were good readers not because they were good at reading, but because they had greater resources at their disposal. On this view, if the capacity of WM is an abiding disposition, independent of a particular task, then span measures should correlate well with reading ability regardless of the nature of the processing task (i.e., reading, doing arithmetic, etc.). Indeed, the authors showed that they could predict reading ability when simple arithmetic, combined with word recall, was substituted for sentence processing.

In light of this, Conway et al. (2005) make a clear distinction between the older (and, more traditional) concept of STM and the newer (and, more active) concept of working memory capacity. According to the authors, the former reflects primarily domain-specific skill, whereas latter reflects primarily domain-general attention. Moreover, in claiming WMc as domain general, Conway et al. cite the work of Kane and Engle (2002, p.638):

> *By "executive attention" we mean an attention capability whereby memory representations are maintained in a highly active state in the face of interference, and these representations may reflect action plans, goal states, or task-relevant stimuli in the environment. Critical to our view is that, while the active maintenance of information can be useful in many situations, it is most necessary under conditions of interference. This is because in the absence of interference, task-relevant information or goals may be easily retrieved from long-term memory as needed. Under interference-rich conditions, however, incorrect information and response tendencies, are likely to be retrieved, and so such contexts set the occasion for the reliance on active maintenance of information* (Kane and Engle, 2002, p. 638).

In short, there appears to be a domain-general 'executive attention' aspect to WM that is *not* the result of either the storage or processing limits per se, but rather an "*emergent consequence of combining these two requirements*"—the essence of the psychometric approach (Jarrold & Towse, 2006, p.45). Thus, the view of this present paper of WM as an attention control mechanism is analogues to the concept of what Baddeley and Hitch (1974) called the *central executive* in Figure 1.2(a), and what Norman and Shallice (1986) labeled as the *supervisory attentional system* in Figure 1.2(b).

In the following chapter, several theoretical accounts that have been developed to explain the effects of stress ('anxiety') on cognitive tasks will be presented. These theoretical accounts (so-called 'cognitive interference theories') are of direct relevance to this thesis and, as discussed below, provide a valuable framework within which to understand cognitive task performance. Furthermore, they inherently assume that the adverse the affects of anxiety on cognitive processing (or attentional control) center on the central executive component of Baddeley's (1986, 2001) WM system.

2 Chapter Two: Theoretical Context

2.1 Theoretical Approaches to Anxiety and Cognition

Anxiety is perhaps the most cited stress condition by which students of emotion have studied complex cognitive behaviour and memory processes, specifically those related to WM (e.g., Deraskshan & Eysenck, 2009; Eysenck & Derakshan, 2011; and Eysenck, Derakshan, Santos & Calvo, 2007).

The explanation that high-anxious individuals may simply be less practiced or skilled in certain tasks (e.g., reading, doing arithmetic)—deficits owed to *ability* and not threat-based cognitions per se—has been challenged by a wealth of data (Conway, Kane & Engle, 2003; and Kane et al., 2004). This makes a direct association between domain-specific skill and anxiety unlikely but instead supports the view that the effects of anxiety on cognition could be due to the amount of resources available (e.g., Kane et al., 2004), as proponents of cognitive interference theory (so-called resource depletion models) might argue.

2.1.1 Cognitive Interference Theory (CIT; Sarason, 1988) [2]

Among the central tenets of Sarason's model are that negative mood states are often associated with high levels of task-irrelevant thoughts, and that these task-irrelevant thoughts work by "direct[ing] 'attention in idiosyncratic ways" (Sarason, 1988, p.3). According to Sarason, task-irrelevant thoughts can be sub-categorised into two components, worry and anxious arousal (see Bradley, 2000); however it is the mental worry facet—that is, the *anxious apprehension*—that explains the repeated poor performance of high-anxious individuals (Derakshun & Eysenck, 2009). Hence, when

[2] Here we consider Sarason's (1988) CIT, which was a precursor of Processing Efficiency Theory (Eysenck & Calvo, 1992), itself, a precursor of Attentional Control Theory (Eysenck et al., 2007). As such, the present section begins with an overview of the two theories that undergird the more specific hypotheses of ACT.

individuals experience negative mood states (i.e., anxiety), the concomitant threat-based cognitions work to then preempt—i.e., literally consume—the limited capacity ('attentional resources') of WM.

This resource-sharing view, according to Eysenck (1992) has, however, two shortcomings. First, it is an oversimplification to assume that threat-based cognitions lead to a maladaptive response. Indeed, despite its negative effects, anxiety likely evolved as an adaptive response, as a motivating factor that compelled an individual into action. For example, there is data where anxious individuals show comparable performance to low anxious individuals on tests of verbal (Darke, 1988b) and grammatical reasoning (Derakshan & Eysenck, 1998). Together, these results stand in contrast to the prediction that anxious individuals perform necessarily worse than low anxious individuals. In fact, explanations, which will be documented below, appear to differentiate between *performance effectiveness* (generally, the quality of task performance) and *processing efficiency* (generally, the resources or effort used).

Second, CIT fails to fully account for *how* threat-based cognitions relate to the architecture (or functioning) of the WM system. Stated differently, it would seem important for theories of cognition to specify which if any mechanisms of WM are most directly affected by anxiety. As it is, cognitive interference theory simply posits that the experience of anxiety involves task-irrelevant processing, and that those task-irrelevant thoughts work to consume (or compete for) a common resource pool (e.g., Derakshan & Eysenck, 2009).

2.1.2 Processing Efficiency Theory (PET; Eysenck & Calvo, 1992)

In 1992, processing efficiency theory (PET) was put forward, in large part, to address the two afore mentioned lacunae ("gaps") of cognitive interference theory. Among the central tenets of PET is the distinction between:

(i) **Performance Effectiveness** (usually indexed by standard behavioural measures, such as the quality or accuracy of task performance); and

(ii) **Processing Efficiency** (usually indexed by response time, with efficiency decreasing as more processing resources are used).

Unlike CIT, PET makes the assumption that threat-based cognitions impair processing efficiency to a greater extent than performance effectiveness. In other words, the task-irrelevant activities engendered by worry are thought to instigate a control system that may allocate extra processing resources, if needed, to a given task (Eysenck & Calvo, 1992). Thus PET extends CIT by postulating a mechanism through which performance effectiveness may *not* be impaired. The argument is that negative mood states or threat-based cognitions may work to instigate the use of compensatory strategies (e.g., auxiliary processing resources), which, while inefficient, may work to improve task performance.

A second assumption of PET concerns the cognitive architecture of WM most affected by anxiety. Importantly, a core feature of PET is that the effects of threat-based cognitions on cognitive processing center on the central executive of Baddeley's model (1986, 2001) or WM system. The assumption is that task-irrelevant processing affects the entire WM system, but more specifically, affects the central executive, and to a lesser extent, the phonological loop (see Figure 1.2b, Chapter 1).

Unfortunately, this explanation does not account for any lower-level functions specific to the nature of the task being performed, nor does it consider the degree of controlled processing—attentional control—necessary to complete the task. Thus, the notion that mood states impair the cognitive processing of the central executive is rather imprecise, not least because it fails to specify which, if any, lower functions are most aversely affected by negative mood states (e.g., anxiety; Eysenck et al., 2007).

In addressing this issue, Miyake et al. (2000) used latent variable analysis to fractionate the central executive into three partially separable (but partially inter-dependent) lower level functions. These were:

1. Inhibition	"One's ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary" (p. 57); this involves using attentional control to override the tendency to produce a more automatic response.
2. Shifting	"Shifting back and forth between multiple tasks, operations, or mental sets" (p. 55, but see also Monsell, 2003); this involves the disengagement of task-irrelevant information and the subsequent active engagement of task-relevant information (i.e., adaptive changes in attentional control); and
3. Updating	"Updating and monitoring of working memory representations" (p. 56); this involves the transient storage of information rather than attentional control, unless under stress.

In addition to the lack of specificity, PET does not account for the apparent effect of distracting stimuli on high-anxious individuals. This is important given the accruing evidence that anxious individuals are more impaired by distracting stimuli than are low-anxious individuals. As to the particular nature of the distracting stimuli, PET focuses predominantly on neutral or non-emotional stimuli (Keogh & French, 2001) than on conspicuous or threat-related stimuli. Again, this is important given the compelling evidence that anxious individuals are more affected by threat-related stimuli (especially physiological threat) than are low-anxious individuals (Eysenck et al., 2007).

2.1.3 Attentional Control Theory (ACT; Eysenck et al., 2007)

In response to the theoretical limitations outlined above, Eysenck et al. proposed ACT as a major extension of PET (cf. Derryberry & Reed, 2002). Importantly, the central tenet of PET—the distinction between *effectiveness* and *efficiency*—is now subsumed within ACT; however, the theory extends the scope of the PET and is more clear about the effects of anxiety on the lower level functions of the central executive.

2.1.3.1 Attentional Control and the Theoretical Predictions of this Thesis

Importantly, Eysenck et al. (2007) cite the definition of *control* used by Yantis (1988), who focused on whether attention was regulated in a top-down, goal-driven fashion (*controlled processes; endogenous attention*) or whether it was regulated in a bottom-up, stimulus-driven fashion (*driven processes; exogenous attention*). Among the central tenets of ACT are that negative mood states disrupt the bi-directional balance between two attentional control systems: one influenced maximally by task goals (i.e., the goal driven system) and the other influenced maximally by salient stimuli (i.e., the stimulus-driven system; Corbetta & Shulman, 2002).

According to ACT, negative mood states influence of the stimulus-driven system over the goal-driven system. In other words, the effects of negative mood states are associated with an attentional bias for salient stimuli, which, within the scope of ACT, are most pronounced when under situational factors such as anxiety. Thus, the crucial contribution of this research is that it follows from the work of Miyake et al. (2001) and Friedman et al. (2004), who were among the first to explore the lower level functions of the central executive and their relation to the goal-driven system. Hence, the main focus of the theoretical predictions in this thesis are the effects of stress in the form of anxiety on the central executive, specifically on the third lower-level function identified by Miyake et al. (2000, 2001), namely the *updating* function (for review, see Eysenck et al., 200700). The following section—section 2.2—reviews the updating function from its relation to WM tasks to its current reliability and use, or misuse, in the cognitive literature in order to support the statistical and methodological techniques employed in studies 1 and 2 of this thesis.

2.2 Attentional Control and The Updating Function of the Central Executive

The assumption that threat-based cognitions increase the influence of the stimulus driven system (via automatic processing of salient stimuli) means that anxiety typically reduces the influence of the goal-directed system (e.g., Eysenck & Derakshan, 2011). Although difficult to define operationally, the two systems offer a somewhat of a robust framework within which to consider the effects of threat-based cognitions in the form of anxiety on cognitive processing.

This position is similar with respect to Baddeley's (1986, 2001) notion of the immediate-memory system, the central executive. As discussed earlier, it is misguided (and therefore imprecise) to regard the central executive as a pool of general processing capacity, and so hypotheses framed in these kinds of terms are somewhat vague and difficult to interpret. Instead, and in the words of Eysenck et al. (2007), "what is needed is a theoretical approach focusing on the *lower level* functions that are related to the goal driven system and to the central executive" (p.338; emphasis added).

One such lower level function is the updating function. According to Miyake et al. (2000), the updating function involves modifying (and continuously monitoring) the content of information according to newer and more immediate information. One of the main empirical methods for testing this function is one in which two tasks compete for the same resource pool; tasks—specifically, memory span tasks—are devised in which members of various categories (e.g., digits) are interleaved with the presentation of a limiting, secondary task, such as verifying equations.

Two tasks that that measure this function are the *R*span and operation span (*O*span). As discussed earlier, the *R*span is typically assessed by having participants read a series of sentences, and, in some cases, read and verify the veracity of those sentences, while attempting to track terminal words for subsequent recall. In a similar fashion, the *O*span involves online processing in which sentence processing is substituted with simple arithmetic. Participants are presented with arithmetical problems, each followed by a target word, and *O*span (like the *R*span) is defined as the maximum number of items for which a subject can correctly recall terminal words (see Figure 2.1).

Two Tasks Measuring the Updating Function

Reading Span (WMc; Set Sizes 2 – 5)	**Operation Span (WMc; Set Sizes 2 - 5)**
The day ate the clock. GAME	IS (9 / 3) – 2 = 2 ? GAME
The postman jumped the fence. NERVE	IS (8 / 4) – 1 = 1 ? NERVE
The country signed a treaty. WAX	IS (6 x 3) – 2 = 11 ? WAX
The picture drew a boy. TIN	IS (10 / 2) + 4 = 9 ? TIN
The queen loved the king. CHURCH	IS (4 x 3) + 2 = 14 ? CHURCH

Figure 2.1 Illustration of Daneman and Carpenter's (1980) Reading Span Task and Turner and Engle's (1989) Operation Span Task. The above examples each have a set size of .5. WMc = Working Memory Capacity. Updating tasks (i.e., WMc tasks) are thought to engage executive attention processes because they require the participant to keep some information active and quickly retrievable while simultaneously shifting (periodically) their attention to some other processing (distracting) task (Baddeley & Hitch, 1974).

Thus it could be argued that memory span tasks measure transient storage of immediate information (or memory per se) rather than being directly concerned with attentional control. A prediction from ACT, therefore, would be that threat-based cognitions impair "tasks involving the updating function *only* under stressful conditions" (Eysenck et al. 2007, p.347, emphasis added). Under more onerous conditions (i.e., test or evaluative conditions), the overall constraints on the central executive are thought to increase and, as a result, the probability that anxiety will reduce the efficiency of the goal-driven system is thought to increase. Indeed, it follows that WM tasks may provide a relatively pure measure of WM capacity or immediate storage; however, if (and when) administered under more stressful conditions, such as in the presence of a physiological stressor, then the task itself may become more a measure of attentional control than of immediate storage (see Table 2.1)

Table 2.1
Sample of Studies Showing Effects of Anxiety on the Updating Function of the Central Executive

Source	Paradigm/Task	Stressor	Effect	Function
Santos & Eysenck (2005)	Operation Span	Close Observation by Experimenter; Failure Feedback	No Effect	Updating
Wolf & Smeets (2009)	Operation Span	Cold Pressor	Negative	Updating
Schoofs, Preuss, & Wolf (2008)	Operation Span	Cold Pressor/ Psychosocial	Negative	Updating
Calvo, Eysenck, Ramos, & Jimenez (1994)	Reading Span	High Evaluative/ Test Conditions	No Effect	Updating
Calvo, Ramos, & Estevez (1992)	Reading Span	High Evaluative/ Test Conditions	No Effect	Updating
Calvo & Eysenck (1996)	Reading Span	High Evaluative/ Test Conditions	No Effect	Updating
Darke (1988a)	Reading Span	Ego Threat Instruction	Negative	Updating

Note: According to Attentional Control Theory, memory span tasks reflect a central executive limitation, specifically an updating limitation (Miyake et al., 2000). Accordingly, such tasks are thought to provide a relatively pure measure of WM capacity or transient storage. However, if (and when) administered under more stressful conditions, such as in the presence of a physiological stressor, then the task itself may become more a measure of attentional control than of immediate storage (Eysenck et al., 2007).

2.2.1 Stress, Working Memory and the Updating Function

Several authors have demonstrated that there are no effects of threat-based cognitions on the updating function assessed by either the *R*span or *O*span when conditions are non-stressful. For example, Calvo and colleagues (Calvo & Eysenck, 1996; Calvo, Eysenck, Ramos, & Jime´nez, 1994; and Calvo, Ramos, & Estevez, 1992) carried out a number of studies in which subjects read texts under conditions of non-stress. Across all three studies, there were non-significant effects of anxiety on *R*span performance, and this was under non-stress conditions not contaminated by threat-based cognitions. In a similar study, Santos and Eysenck (2005) compared *O*span performance under conditions of stress or non-stress. As expected, the authors found no observable difference on the updating function assessed by the *O*span when conditions were non-stressful.

When stressful conditions are used the findings are less clear—being somewhat "inconsistent and difficult to interpret" (p. 347, Eysenck et al., 2007). On the one hand, there is data from Darke (1988a) and Calvo et al. (1992) who found high anxiety was associated with impaired *R*span performance under conditions of stress. On the other, there is data from Sorg and Whitney (1992) and from Santos and Eysenck (2005), who found no clear difference between low and high anxious groups under conditions of stress (see Eysenck et al., 2007, for a review). How then to explain such empirical discrepancies?

Conflicting results reported by Eysenck et al. (2007) may be explained on account of the large number of different stress inducing protocols (or administration procedures). For example, the studies reviewed by Eysenck predominantly used psychological or psychosocial stressors such as ego-threat instructions (Darke, 1988a) and close observation (Santos & Eysenck, 2005), with equivocal results. These approaches, however, can be contrasted with other approaches, which have used stronger physiological stress inducing components (e.g., threat of shock) and found clear differences between high-and-low anxious groups (see Dickerson & Kemeny, 2004; but see also Table 2.1). Thus, the disharmonious results reported in the stress and attention area, especially those reviewed by Eysenck et al. (2007), may be explained by assuming that more difficult WM tasks require a greater cognitive workspace and thus might be more prone to the effect of negative mood states in the form of anxiety.

3 Chapter Three: Open Questions

3.1 Questions Guiding the Current Research: Study 1

The first aim of this thesis was to test the effect of administration method on the predictive utility a commonly used updating task, the WM task. While the theoretical background presented in chapters 1 and 2 raises some intriguing questions, the most apparent perhaps is the influence of stress.

3.1.1 To What Extent Does Stress Influence the Updating Function of the Central Executive?

Psychometric studies have long-established the negative effects of threat-based cognitions on cognitive processing (see Schoofs et al., 2008, and Wolf et al., 2001), yet the results are not fully conclusive and seem to be contingent on the stress inducing protocol as well as the specific stressor. According to Wolf and Smeets (2009), there are at least two types of protocols—those that emphasise a psychological effect (e.g., social stress) and those that otherwise emphasise a physiological/pathological effect (e.g., cold pressor stress). However, although these two protocols are clearly related, it is unclear from attentional control theory whether they affect the updating function in the same way or even to the same degree (Eysenck et al., 2007).

3.1.1.1 Psychological Stress and the Ospan — Administered as a Primary Task

The essence of psychological stressors is that they involve threat-based components that engage cognitive resources, sometimes with a social-evaluative component. One often-used (and sometimes misused) stress inducing protocol is the 'experimenter-paced *O*span' in which time parameters (e.g., item presentation rate) are controlled by the experimenter. Using this approach, Friedman and Miyake (2004) discovered that experimenter-paced tests were more strongly correlated with reading ability (r = .55) than with self-paced or self-administered tests (r = .28). They argued that this was because, relative to self-paced tests, experimenter-paced tests are less amenable to the use of idiosyncratic or mnemonic strategies (e.g., covert rehearsal).[3] Thus, in terms of psychological stress, there is of the course a general loss of control, as well as both a definite time pressure and clear expectation that a series of items (words) should be recollected (Conway et al., 2005).

3.1.1.2 Physiological Stress and the Memory Span — Administered as a Secondary Task

Given the methods with which WM tasks are administered can vary widely, it is somewhat troubling that many well-established methods allow for time *beyond* that needed to complete the processing task. One solution to eliminate this possibility altogether is to administer the task as a realistic (or naturalistic) *secondary* task (e.g., Salvucci, 2001, 2002, 2006, 2007).

In this regard, the present study takes as its starting point several conclusions into the effects of mobile use on driver performance.[4] For example, Alm and Nilsson (1995) used a car-following task in which a lead car would occasionally decelerate at an average of 3 m/s^2 while the participant either focused on the car in front (control), or periodically performed a secondary WM task (task group). Performance on the WM task (so-called divided attention task) was thought to index the number of items (i.e.,

[3] Two recent studies (Friedman & Miyake, 2004; St. Clair-Thompson, 2007b) support the view that tests of WM must first be qualified by whether or not the updating task (i.e., WM task) is participant- or experimenter administered. When task administration parameters (i.e., item parameters) are *not* controlled by the experimenter during updating tasks, the processing time (not accuracy) positively correlates with performance on the storage component, indicating that participants in these test situations (particularly, self-paced test situations) are in fact altering their processing performance (e.g., slowing down) to engage in rehearsal and other idiosyncratic or mnemonic strategies. On the other hand, unlike participant administered tests, experimenter-paced test scores and processing times are correlated with higher-order cognition (see Unworth et al., 2009 for a review).

[4] When considering the time-sharing ('co-operation') problem of phone usage while driving, there has often been an assumption that co-operation improves when tasks are dissimilar (or cross-model) than when they are similar. In this regard, it may be assumed—albeit wrongly—that because the two tasks are dissimilar, that is, in separate modalities, that there should be little or no interference from the phone task on driver performance. Yet, this is not what models of cross-modal interference tell us (Wickens, 1992). In fact, having to perform two tasks concurrently is likely to increase the overall demands on the central executive, thereby creating *high mental workload* conditions and thus physiological stress (see Lehrer et al., 2010).

words) a driver could retain in storage and bring to the focus of attention, which, for the task group, was *unrelated to rehearsal* (Friedman & Miyake, 2004) or any other idiosyncratic or mnemonic strategy (see Figure 3.1).

Primary Task	**Secondary Task:**	**Secondary Task:**
	Stage 1[a]	**Stage 2**[b]
	Grandmother baked bread	Bread
Simulated Driving	Thermometers tell the time	Time
	Potatoes grow on trees	Trees
	Slippers are sold in pairs	Pairs
	The policeman ate the apple	Apple

Figure 3.1 Two-Stage Model of Alm and Nilsson's Divided Attention Task. The primary task in Alm and Nilsson's (1995) research was to drive behind a car where the lead vehicle would on occasion perform some hazardous maneuver and leave the driver in a 'safety critical' situation. For those assigned to the task group, a secondary task was completed on a hands-free mobile phone, which involved two stages.

[a] Stage 1. Drivers were required to do two things (1) listen to five unrelated sentences in the form X does Y, and then report, after each sentence, the veracity (or sensibility) of the presented sentence.

[b] Stage 2. As to the storage function, drivers were asked to recall (or report) the last word of each sentence for subsequent recall, i.e., the memorised list of unrelated words. Here the WM task was essentially equivalent to the carrying on of a difficult conversation.

When combined with driving, the WM task was thought to increase the overall constraints on the central executive. The results obtained by Alm and Nilsson (1995) showed exactly this—the carrying on of a difficult conversation increased drivers' task load, as measured by the NASA-TLX, with the consequence (or effect) that reaction time to onset of a 'safety critical' situation was impaired (cf. Salvucci, 2002). No effect, however, on drivers' lane position could be detected, suggesting that drivers may have had some management over driver performance.

This capacity to manage the effects of threat-based cognitions is clearly important to other personnel in similar multi-task environments. Piloting an aircraft, for instance, involves not only the precise control of a complex system but also the co-ordination of several sub-processes that, like driving, make use of the aviator's vigilance, cognitive capacity and motor skill. Indeed, this dynamic array of skills makes flying an ideal assignment in which to investigate how aviator's (or individual's) cope with complex cognitive tasks and how models of immediate-memory and flying can be used to predict divided attention tasks (see, for example, Bednarek, Truszczyński, & Wutke, 2013, Experiment 1).

To summarise, this thesis focused on the predictive utility of WM (as a primary and/or secondary task) and addressed two specific aims. The first aim was to determine whether the methods with which the WM task is administered (within the framework of ACT) affect the predictive utility of the resulting measure, using simulated flight as the specific criterion construct of interest. Although *both* administrative methods use the same psychometric approach, the divided attention task predicts 'flight' performance from a primarily secondary cognitive task (cf. Salvucci 2002). The second aim was to explore the components of WM, in the interest of further understanding what the task actually measures: is it, as Sub et al. (2002) notes, the *"storage capacity, processing capacity, the combination of both"* (pp. 285–286) or indeed something else.

3.1.2 What do Memory Span Tasks (so-called WM or Updating Tasks) Actually Measure?

As was previously described, tests of WM were designed to engage attentional processes by forcing WM storage (and rehearsal) in the face of ongoing processing (Conway et al., 2005). The fact that these tests are so sensitive to many practically and theoretically important behaviours points to their utility across a number of domains, and provides a theoretical starting point from which to understand why, and how, these tests correlate so well with measures of higher-order cognition.

Perhaps the best starting point is to consider the individual components that make up or comprise the memory span task. If the capacity of WM is the ability to recall information (as Daneman & Carpenter originally asserted), then two measures of data are available: one from the storage (i.e., recall) component of the task one from the processing (i.e., accuracy) component of the task. However, as is often the case with span tasks, the typical measure of interest is often the recall score from the storage component of the task (see, for example, Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005, for a review).

Although often overlooked, the processing component should also offer some predictive utility (Unworth, Reddick, Heitz, Broadway & Engle, 2009). For example, correlations between processing accuracy and both storage accuracy and various measures of higher-order cognition (Daneman & Carpenter, 1980) suggest that there may be ample variation in the processing performance of the task. Thus, the possibility remains that processing and storage may actually share considerable variance (if not unique variance) when predicting complex cognitive behaviour (Friedman & Miyake, 2004; and Unsworth, Heitz, Schrock, & Engle, 2005b). If this analysis is correct, then variation in updating tasks (so-called tests of WM) can arise from three independent sources, namely storage capacity, processing capacity or the potentially emergent consequence of combining these tasks (Jarrold & Towse, 2006), although which is primarily involved remains open to investigation (Süb et al., 2002).

3.1.2.1 To What Extent are Individual Differences in Cognitive Task Performance Domain-General (WM as a Fixed Capacity) or Domain-Specific (WM as an Acquired Skill)?

The first question is whether WMc reflects ‘something’ beyond the storage and processing component. As was previously stated, there is an increasing interest in the observed relationship between memory span tasks (i.e., updating tasks) and cognitive abilities (e.g., Bayliss, Jarrold, Gunn, & Baddeley, 2003; and Colom, Rebollo, Abad, &

Shih, 2006).

In their review of individual differences in complex cognition, Sohn and Doane (2003) highlight two contrasting loci: a *domain-general account* (i.e., WM as fixed capacity) and a *domain-specific account* (i.e., WM as an acquired skill). Of further interest to this thesis is whether individual differences in cognitive task performance are due to differences in WMc ('domain-general attention'), pre-existing ability ('domain-specific skill'), or both. However, given the view of the current research—WM as executive attention—the specific research question is whether WMc (domain-general attention) would reduce the importance (unique variance) of pre-existing ability during complex cognition (Engle, 2002; see Figure 3.2) or flight performance, specifically.

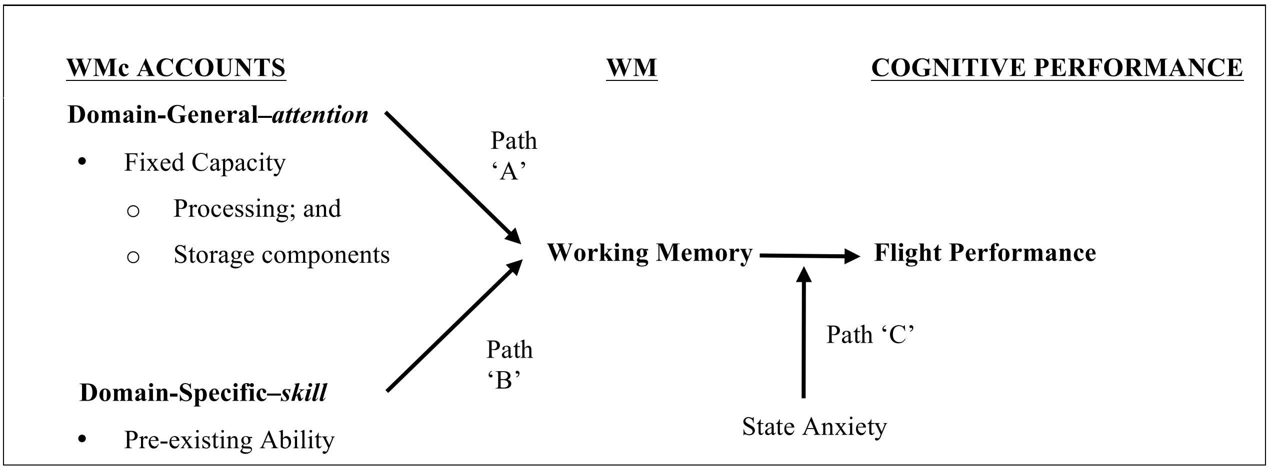


Figure 3.2 An illustration of the Domain-general Account and Domain-Specific Account on Cognitive Performance

Finally, it is worth considering the interplay between anxiety and WMc against the theoretical framework of ACT (Eysenck et al., 2007). As was previously noted, cognitive interference theories suggest that threat-based cognitions ('anxiety') predict adverse effects on performance *effectiveness* and processing *efficiency.* However, a central tenet of ACT is that it also accounts for situations in which individuals *may* compensate for task-irrelevant processing. The argument is that individuals who have high levels of threat-based cognitions, but who also have high levels of WMc (i.e., auxiliary processing resources), are better *able* to compensate for deficient use of attentional control with additional effort. A second question, therefore, is to what extent are individual differences in WM (as a fixed capacity) useful for covering or limiting the stress response? Thus, it was predicted that high-anxious individuals may perform on par with low-anxious individuals in terms *effectiveness* (i.e., task quality), but would, in terms of cost, be less efficient in achieving parity.

3.2 Questions Guiding the Current Research: Study 2

The main aim of Study 2 was to extend the work and findings put forward in Study 1. Thus, the focus of the theoretical predictions in Study 2 are the effects of threat-based cognitions—specifically, induced anxiety—on cognitive processing, in particular those placing substantial limts on the central executive.

A limitation of Study 1 (at least conceptually) was that it inherently assumed the presence of stress. According to Shackman et al. (2006), one methodological desiderata for studying the effects of anxiety on cognition is that "*lasting affect must actually be elicited*" (p. 42). In other words, if the goal of the researcher is to characterise how task-irrelevant anxiety influences cognitive processing, then the research paradigm must be capable of actually eliciting a true and lasting stress response (Koolhaas et al., 2011).

3.2.1 Threat of Shock as a Stress-Inducing Protocol

One approach to clarifying the effects of a given threat-based cognition is to reproduce it in healthy individuals and to examine its effect on performance. For symptoms of anxiety, this can be achieved through the infrequent and unpredictable administration of shocks (or, more specifically, the 'threat-of-shock'; Grillon, 2008a; 2008b). Indeed, studies using this procedure have found it to be a relatively pure and automatic elicitor of anxiety, unconfounded by non-target mood states, such as disgust or anger (Grillon, 2008a).

In accord with empirically informed theories of cognition and attentional control (Eysenck et al., 2007), it was predicted that negative mood states engendered by the threat of shock would provide a longer lasting and thus more realistic affect response (Shackman et al., 2007). Thus, a goal of study 2 was to examine whether threat of shock (in a flight task) would alter cognitive processing and mimic the cognitive *inflexibility* seen in anxious individuals, particularly those with low-WMc.

A second methodological desideratum for studying the effects of anxiety on cognition is that "*the presence of the intended emotions must be adequately verified*" (Shackman et al., 2006, p. 42). In other words, if the goal of the researcher is to induce anxiety in a subset of participants, then it is somewhat imperative to collect indices that are capable of verifying the presence of the target affect (e.g., anxiety). Given that a single index cannot fully capture threat-based cognitions, it is necessary to adopt tools that provide information on the ongoing functional state of an individual, namely measures of physiological arousal (Di Nocera, Camilli, & Terenzi, 2007).

3.2.2 To What Extent Can Physiological Data Supplement Self-Report Data?

Stress inducing protocols often fail to fully engender the negative affect that the researcher first set out to elicit (Stemmler, 2003). In their follow-up article to ACT, Derekshan and Eysenck (2009) made a call for future research to go beyond "indirect behavioural measures" (p. 174) of self-reported anxiety. Psychophysiological measures (e.g., skin conductance) and behavioural measures may therefore prove especially advantageous given the specific set of biases associated with self-report data (e.g., Fredrickson, 2000).

Psychophysiological measures, in particular, are advantageous in that they can be continuously acquired, allowing for an unobtrusive online measure of real-time affect (Lee & Liu, 2003). Within this context, psychophysiological measures are useful because they reflect not only task engagement (Schwerdtfeger & Kohlmann, 2004) and workload (Svensson & Wilson, 2002; Wilson & Russell, 2003a,b; Wilson, 2002) but also states of increased effort.

Among the numerous psychophysiological measures, those sensitive to heart rate, eye movement, respiration, and skin conductance are the most common (Huttunen, Keränen, Väyrynen, Pääkkönen, & Leino; and Lehrer et al., 2010). However, of these, galvanic skin response (GSR) and heart rate variance (HRV) are perhaps the "most important for detecting the stress response" (Singh & Queyam, 2013, p. 14). Thus, in addition to self-report measures, the second study employed measures of GSR and HRV to verify the presence of target affect (i.e., anxiety) on subgroups of participants, namely those assigned to either a stress group (threat of shock) or control group (non-stressful condition). In this context, it was of interest whether results of Study 1 could be replicated (and possibly extended) to more stressful conditions—namely, under threat of shock. Thus, the same hypotheses as Study 1 were tested for Study 2, except that this time, physiological data was used to enhance the generalisability of Study 1.

3.4 Summary and Introduction to the Studies.

Among the central tenants of PET and ACT is the notion that the effects of threat-based cognitions on cognitive processing center on the central executive facet of Baddeley's (1986, 2001) WM system. Much evidence (e.g., Corbetta & Shulman, 2002; Posner & Petersen, 1990) supports this view, with the clearest evidence having been reviewed by Eysenck and colleagues (e.g., Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Eysenck et al., 2005).

The assumption that threat-based cognitions impair attentional control (a key function of the central executive) can be related to the view (Friedman & Miyake, 2004) that it involves three lower level functions: inhibition, shifting and updating (e.g., Corbetta & Shulman, 2002). The development of the updating function in particular has been much influenced by the empirical research of Calvo and colleagues (e.g., Calvo & Eysenck, 1996; Calvo et al., 1994; and Calvo, Ramos, & Estevez, 1992), with the most ostensible effects being obtained under conditions of stress although these results are somewhat “inconsistent and difficult to interpret” (Eysenck et al., 2007, p. 347).

Direct comparison of a number of stress inducing protocols should help clarify how stress affects the updating function, and Eysenck et al.’s (2007) attentional control theory may be a useful framework to use. In terms of the effects of stress on the updating function, Wolf and colleagues[5] (e.g., Kuhlmann, Piel, & Wolf, 2005, Schoofs, Preuss, & Wolf, 2008; and Wolf & Smeets, 2009) found inverse relationships between physiological stress and WM performance. These studies do not, however, involve various stress inducing protocols, but rather correlate supraoptimal levels of threat-based cognitions with performance. Where evidence still seems to be lacking is in the area of the effects of stress inducing protocols on WM performance, and how differences in the type of stressor (and its administration) may relate to the updating function.

Apart from this administrative problem, there is also the question of what WMc (i.e., WM performance) actually measures. Kane and Engle (2002) argued that WMc reflects primarily a domain-general attention, and other authors have argued likewise,

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[5] According to ACT, manipulating the type of stressor presented could vary the effects of anxiety. Here there is the issue of whether the Cold Pressor Test (CPT, used by Wolf and colleagues) conforms to the definition of stress proposed by Koolhaas et al., (2011). Reconsidering the stress definition stated earlier, “…a cognitive perception of uncontrollability and/or unpredictability” (p.1292), may suggest a more useful protocol might involve the threat of shock because, unlike CPS, it involves a level of unpredictability.

albeit from a more methodological point of view (Conway et al., 2005). The difficulties of demonstrating this idea seem to derive from studies that have not controlled for pre-existing abilities in their specific criterion construct of interest. Indeed, as Süb et al. (2002) notes, "*which factors of working memory affect which part of the cognitive process … is not well understood. Is it … something beyond storage and processing?*"

Sohn and Doane's (2003) distinction between WM as either a domain-general or domain-specific variable appears to go some way to providing a possible means of understanding what WM performance actually measures. Encouragingly, studies have repeatedly shown that there are no effects of anxiety on the updating function assessed by the either the *R*span or *O*span when conditions are non-stressful (e.g., Calvo, Ramos, & Estevez, 1992). Thus, a conclusion held in common among most of these studies is that updating does not directly involve domain-general attention unless under stressful conditions (Eysenck et al., 2007).

More generally, ACT makes various predictions about the strategies used by high-anxious individuals when their processing becomes inefficient. Indeed, the *motivating* effects of stress on the updating function remain largely unknown and, as Derakshan and Eysenck, (2011) notes, "it is a matter of future research to elucidate those circumstances" in which the substantial (but inefficient) recruitment of processing resources may occur (p. 959). In other words, it seems most intriguing to investigate whether the aversive effects of threat-based cognitions may be overcome.

Finally, in the wide field of self-help and stress induction studies there have been relatively few studies that have manipulated stress although this situation has more recently improved (e.g., Schoofs, Preuss, & Wolf, 2008; and Wolf & Smeets, 2009). Measurement subsequent to the immediate period after the stress inducing protocol is also rare, and researchers and practitioners alike have questioned the veracity of the reported (or intended) target emotion (Shackman et al., 2006).

The two studies reported in this thesis attempt to address several of these gaps by comparing the effects of the use of psychological and physiological, individual-focused, stress inducing protocols on tests of WM (i.e., updating tasks) and higher-order cognition (Study 1). A psychometric approach is used with a stress group (threat of shock) and GSR and HRV measures (study 2) are used to validate the presence of the intended threat-based cognition, namely anxiety. The effects of stress on the psychological and physiological measures are directly compared using attentional control theory as a framework, and self and physiological assessments of stress (i.e., state anxiety) are used as measures for stress (study 2).

In summary, three broad questions were of interest:

(i) To what extent does stress influence the updating function of the central executive?

(ii) To what extent does WMc reflect 'something beyond processing and storage'? Specifically, do individual differences in WMc (i.e., executive attention) reflect a domain-general or a domain-specific component? In other words, is the central executive function of WMc influenced more strongly by domain-general attention (as measured by the processing and/or storage components of WMc) or domain-specific skill (as measured by simulation experience and pre-flight competence); and finally.

(iii) To what extent are individual differences in WM (as a fixed capacity) useful for covering or limiting the stress response? In plainer terms, can anxious individuals overcome the stress response?

4 Chapter Four: Study One

4.1 Introduction

When aviators first took to the skies following the Wright brothers' successful 12-second flight at the beginning of the 20th century, piloting an aircraft was a physical and perceptually demanding task. A century on and with the advent of computer-based avionics, the perceptual-motor demands of flying have decreased, whereas the psychomotor (i.e., conscious mental activity) or cognitive demands have concomitantly increased (Huttunen et al., 2011).

The present research begins by considering two loci that have been related to individual difference characteristics in complex cognition, namely nature (often and hereinafter referred to as the *domain-general* account*,* e.g., Colom & Shih, 2004; Kane et al., 2004; and Turner & Engle, 1987) and nurture (often and hereinafter referred to as the *domain-specific* account*,* e.g., Ericsson & Kintsch, 1995, 1998; and Mackintosh & Bennett, 2003). Although the two accounts differ conceptually, they are similar in that each is structured around a capacity (viz. working memory; WM) which is posited as a crucial factor or facet of complex cognition. The question is raised: “To what extent are individual difference characteristics in complex cognition domain-general (WM as a fixed capacity; WMc) or domain-specific (WM as an acquired skill)?”

4.1.1 Domain-General Account

Conceptualised on the grounds that WM capacity is inherently different across individuals, the domain-general account suggests that performance differences among individuals within a task domain can be explained by an underlying commodity or limited capacity attentional system (Baddeley & Hitch, 1974). When cognitive loads increase to strain capacity, the individual’s ability to maintain information in an active state—via attentional control—is impaired. In this context, individuals with a lesser capacity are purported to be less able to block threat-based thoughts, to store immediate information, or to suppress a habitual response in favour of a more *controlled* choice. If this explanation accounts for the less controlled (more automatic) processing of low WMc individuals, then they—low WMc individuals—should be hurt more in dual-task situations (Ilkowska & Engle, 2010).

4.1.2 Domain-Specific Account

As an alternative to general theories of immediate memory (i.e., WM as fixed capacity), some aspects of WM are viewed as a function of physiological and/or anatomical adaptations. According to Ericsson and Kintsch (1995, 1998), and further elaborated by Ericsson, Patel, and Kintsch (2000), differences in WMc are explained through (i) retrieval structures (elaborate mechanisms), which reflect differences in an individual's knowledge and skill (Mackintosh & Bennett, 2003) and (ii) retrieval cues, which make task-relevant information in long-term WM (LT-WM) more available. In this context, structures are assumed to "relieve" or bypass basic capacities as predictors of complex cognition (Roring, Nandagopal, & Ericsson, 2007).

Given the relationship between WM and cognitive performance across diverse but demanding critical task situations, the current research makes a differentiation to the processes shaping WM as a domain-general or domain-specific variable (see Figure 4.1)

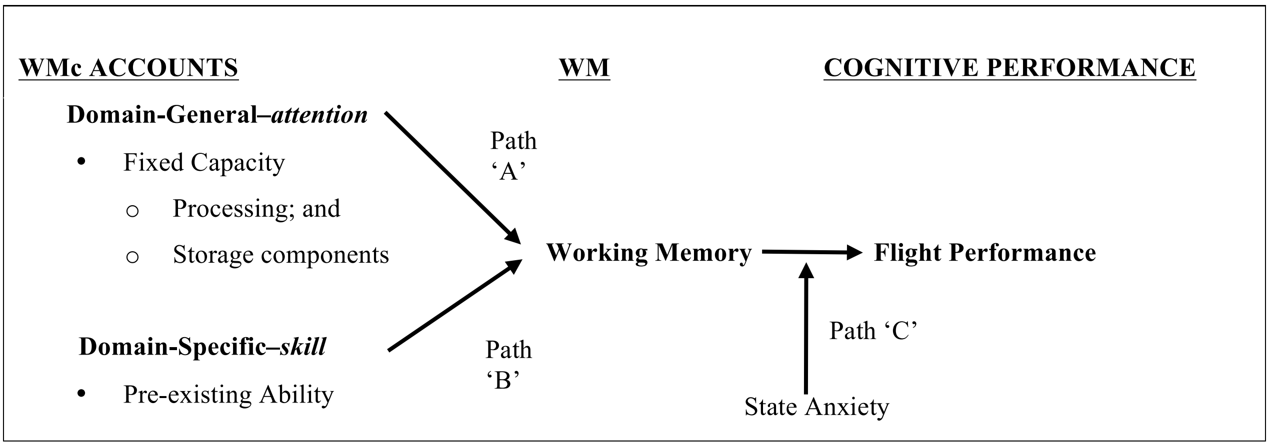

Figure.4.1 An Illustration of the Domain-general Account and Domain-specific Account on Cognitive Performance

4.2 The Present Research

The broad focus of the present research is to investigate the respective roles of WMc and pre-existing ability in a laboratory context. Although the foregoing summary has focused primarily upon individual difference characteristics in complex cognition, there are, of course, many other factors, including threat-based cognitions, and affect, which exert pressure on WM and the regulation of behaviour (Darwin, 1872, and Eysenck et al., 2007).

4.2.1 Attentional Control Theory

The theoretical starting point of this research is the consideration of task-irrelevant anxiety on cognitive processing, suggesting, for example, that threat-based cognition is associated with reduced efficiency of the central executive and WM system as a whole (Eysenck, 1979; Eysenck & Calvo, 1992; Eysenck & Derakshan, 2011; and Eysenck et al., 2007).

A crucial assumption of Attentional Control Theory (ACT) is that anxiety will have a differential effect on:

(i) **Performance Effectiveness:** usually indexed by standard behavioural measures, such as the quality or accuracy of task performance; and

(ii) **Processing Efficiency:** usually indexed by response time, with efficiency decreasing as more resources are used.

Of central importance to ACT is the notion that threat-based cognitions typically impair the former to a lesser extent than the latter, and so inefficiencies—engendered by anxiety—are often indexed by "a smaller ratio of performance effectiveness to use of processing resources" (Eysenck & Derakshan, 2011, p. 959). In this regard, anxiety may affect attention in two ways. First, in simple, repetitive or undemanding tasks, anxiety can be associated with deficient recruitment of attentional control—low levels of motivation mean that high-anxious individuals make minimal use of their potential resources. By comparison, in more demanding tasks, anxiety can be associated with meaningful (but inefficient) recruitment of attentional control—high levels of motivation mean that high-anxious individuals will often compensate for impaired processing. Although research has shown that threat-based cognitions are related to increased motivation and strategy use, the precise manner in which these effects occur is still unclear. Hence the question arose whether, during exposure to stress, WM as a fixed capacity could cover and/or limit the stress response? If high-anxious individuals have auxiliary resources or indeed have sufficient resources, then inefficiencies to the central executive should still be observed (e.g., Roughan & Hadwin, 2011, but see also Eysenck & Derakshan, 2011).

How, then, to study such a complex net of interrelated processes?

4.3 Measurement of Working Memory Capacity as Attentional Control

An overarching assumption of ACT is that the aversive effects of threat-based cognitions (i.e., anxiety) centre on the central executive component of Baddeley's (1986; 2001) WM system (Eysenck et al., 2007). A representative task involving the central executive (namely, the updating function) is one in which to-be-remembered stimuli are interspersed with some processing and/or distracting task.

As an early example of this approach, Daneman and Carpenter (1980) devised the 'reading span task' as a representative task for measuring the capacity of the WM system. In their task, participants were required to combine processing and storage, first reading sentences and, in some cases, verifying the veracity of the sentence, and then, recalling final words. The authors found that this requirement to both process and store information—using complex span/WM procedures—provided a closer approximation to global models of cognition than so-called tests of short-term memory (STM).

Unfortunately, while a strong predictor of many everyday activities (Baddeley, 2003), there are at least two issues presumably germane to the understanding of WM and its relation to cognitive functioning (Ilkowska & Engle, 2010). First, there is the question of what the WM task actually measures: is it, as Sub et al. (2002) notes, "*the storage capacity, processing capacity, the combination of both, or something beyond storage and processing?"* (pp. 285–286). Although the components of WM have been substantially studied, less research has investigated the various features of the processing component (i.e., speed or accuracy) to the number of studies that have explored the correlation between the storage component and higher-order cognition (Unsworth et al., 2009). Nevertheless significant correlations have been reported between higher-order cognition and various features of processing, particularly *speed* (e.g., Barrouillet & Camos, 2001, Exp 1; and St.Clair-Thompson, 2007a) and *accuracy* (e.g., Salthouse, Pink, & Tucker-Drob, 2008), suggesting that there may be adequate variability in the processing component (e.g., Unsworth et al., 2005b).

Second, and more importantly, WM tasks have been criticised as imposing "few demands on attentional control" (Eysenck et al. 2007, p. 347). According to Miyake et al. (2001), WM tasks primarily involve the *updating function* of the central executive, and are therefore not directly concerned with attentional control. When combined with stress, however, the overall constraints on the central executive are thought to increase, and so, according to ACT,

> *"Anxiety impairs processing efficiency (and sometimes performance effectiveness) on tasks involving the updating function only under stressful conditions".* (Eysenck et al., 2007, p. 347,).

Empirical evidence to support this claim, however, is not fully conclusive and seems to be contingent on the stress inducing protocol as well as the stressor. For example, Calvo and colleagues (Calvo & Eysenck, 1996; Calvo et al., 1994; Calvo, Ramos, & Estevez, 1992)—as well as other investigators reviewed by Eysenck et al. (2007)—used protocols that emphasised a psychological or psychosocial effect (e.g., close observation), with results being “inconsistent and difficult to interpret” (Eysenck et al., 2007, p. 348). By contrast, more recent studies have used physiological stress inducing protocols and, with some consistency, found clear differences between low-and-high anxious groups (e.g., Schoofs, Wolf & Smeets, 2009).

Taken together, these results suggest that both psychological and psychosocial stress-inducing protocols are less useful in drawing out differences in anxiety than are physiological stress-inducing protocols. In fact, some researchers have speculated that psychological stress conditions may not add any additional burden on the central executive; rather, they, like non-stress conditions, are notoriously fleeting and can easily be suppressed (Shackman et al., 2006). However, given that researchers use psychological (Calvo & Eysenck, 1996; Calvo et al., 1994; Calvo, Ramos, & Estevez, 1992) and physiological protocols (Kuhlmann, Piel, & Wolf, 2005; Schoofs, Preuss, & Wolf, 2008; and Wolf & Smeets, 2009) interchangeably in the self-help and WM area (sometimes with little or no justification) these types of stress inducing protocols should be compared.

The current study was, therefore, designed to specifically investigate the effects of administration method on the predictive utility of a commonly used updating task, the WM task. Specifically, the study compared two WM tasks differing in the limits or constraints they put on the central executive. The first was an experimenter-paced operation span (*O*span) in which task administration parameters were monitored by the experimenter (psychological stress). The second was a divided attention task in which the WM task was administered as realistic secondary task. With regard to the latter, several applied studies have reported people to be able to reason effectively while simultaneously carrying out other purely cognitive secondary tasks (WM task;

Baddeley, 1986); specifically those studies investigating the dual constraints on human cognitive and perceptual-motor abilities (e.g., driver distraction; Alm & Nilsson, 1995, and driver multi-tasking; Salvucci, 2006; see also chapter 3).

4.4 Piloting an Aircraft as a "Stressful" Complex Cognitive Task

Clearly piloting an aircraft involves the coordination of several processes that make use of the person's vigilance, cognitive capacity, and motor movements. In the course of even the most low-level, low-load flight phase, an aviator must manage a number of tasks often in stepwise and/or interleaved fashion and in combination with a large number of responses to a wide variety of stimuli, including visual and auditory information from inside and outside the aircraft (Lee & Liu, 2003). Human error, in particular, and issues relating to the management of a complex system are a significant source of aviator error, and have contributed to both accidents (see National Safety Transportation Board e.g., Loukopoulos, Dismukes, & Barshi, 2003) and incidents (see Aviation Safety Reporting System incident reports; e.g., Dismukes, Young, & Sumwalt, 1998).

One particular aspect of aviator error that has garnered much attention from Aviation Medical Examiners (AMEs; Robert, Field, & Scragg, 2002) and aeromedical practitioners alike (Sen, Akin, Craft, Canfield, & Chaturvedi, 2007) is that of "aviator workload" —namely, the effects of multitasking while performing some secondary task. Indeed, it is generally assumed that, unlike most fields of self-help and coping, subclinical levels of otherwise negligible importance may affect aviators in ways that seriously worsen (and thus impair) their attention, vigilance and WM performance (Skinner & Simpson, 2002).

In reviewing certain factors that impair particularly the WM functions of an aviator, Stokes and Kite (1994; 2003) highlight a rather pervasive error in many considerations of general theories of immediate memory; namely, citations that reference the Yerkes-Dodson inverted-U curve (1908), often presented uncritically as a general law that there exists an optimal combination of arousal and performance, and that 'good' performance diminishes equally if the subject (or aviator) is under too little or too much stress. The authors go on to provide several criticisms of the use of the Yerkes-Dobson curve including, for example, (1) the fact that the "curve" is foremost counterintuitive, lacking face-validity, and then, (2) likening the "curve" to the Bermuda Triangle in terms of its application to poorly defined situations (for a thoughtful discussion of these explicit criticisms see Sen et al., 2007).

Taken together, the psychological limits of aviation are clearly sensitive to stress and cognitive processing (Lee & Liu, 2003). It is important, therefore, to study cognitive processing (of which WM is part) in aviation to detect mental overload on the basis of aviator's WM, and thereby obtain important data to improve aviation safety and in-house training. Information on features of cognitive processing (domain-general/ domain-specific features) can then be used for overcoming capacity limits; however, more practically, also for self-monitoring, e.g., to facilitate aviators' awareness of mental disorders at subclinical levels. Indeed, the dynamic array of skills required of aviators, therefore, makes flying an ideal assignment in which to investigate how aviator's cope with complex cognitive tasks and how models of immediate-memory and flying can predict divided attention tasks (cf. Salvucci, 2007).

4.5 Hypotheses: Rationale for the Present Study

To summarise, this study focused on the predictive utility of WM (as a primary and/or secondary task) and addressed two specific aims. The first aim was to determine whether the methods with which the WM task is administered (within the framework of ACT) affect the predictive utility of the resulting measure, using simulated flight as the specific criterion construct of interest. Although *both* administrative methods use the same psychometric approach, the divided attention task predicts 'flight' performance from a primarily secondary cognitive task (Salvucci 2002). The second aim was to explore the components of WM, in the interest of further understanding what the task actually measures: is it, as Sub et al. (2002) notes, the *"storage capacity, processing capacity, the combination of both"* (Süb et al., 2002, pp. 285–286) or indeed something beyond storage and processing capacity.

Indeed, this often-overlooked notion raises two intriguing questions:

(i) To what extent does WMc reflect 'something beyond processing and storage'? Specifically, do individual differences in WM (i.e., executive attention) reflect a domain-general or a domain-specific component? In other words, is the central executive function of WMc influenced more strongly by domain-general attention (as measured by the processing and/or storage components of WMc) or domain-specific skill (as measured by simulation experience and pre-flight competence); and finally,

(ii) To what extent are individual differences in WM (as a fixed capacity) useful for covering and/or limiting the stress response? That is, can anxious individuals overcome the stress response?

The following hypotheses are proposed.

In order to determine if WMc reflects 'something beyond the storage and processing' component, pathways (a) and (b) were expressed in terms of negative change (see Figure 4.1).

Hypothesis 1: Higher scores on WMc will be associated with a decrease in flight error, after controlling for a person's pre-existing ability (i.e., simulation experience, pre-flight competence, and state anxiety).

Two sub-hypotheses were proposed to compare the effects of stress on *two* tests of WM differing in the constraints or limits they put the central executive (in particular the *updating* function) and the WM system as whole. Here the term 'dynamic' was used to denote correlations obtained from the divided attention task, whereas the term 'static' was chosen to denote correlations obtained from the experimenter-paced *O*span task.

Hypothesis 1a: Higher scores on the processing and/or storage component of Dynamic WMc will be associated with a decrease in flight error, after controlling for a person's pre-existing ability (i.e., simulation experience, pre-flight competence, and state anxiety).

Hypothesis 1b: Higher scores on the processing and/or storage component of Static WMc will be associated with a decrease in flight error, after controlling for a person's pre-existing ability (i.e., simulation experience, pre-flight competence, and state anxiety).

In order to assess the assertion that individuals with greater cognitive resource availability are better able to engage in concurrent task processing, pathway (c) of the interaction model was tested by Hypothesis 2.

Hypothesis 2: State anxiety and working memory capacity (WMc) interact such that flight error will be greater in individuals high in state anxiety and low in WMc, but where state anxiety is high and WMc is high, flight error should be reduced.

Hypothesis 2a: State anxiety and the processing and/or storage component of Dynamic working memory capacity (DWMc) interact such that flight error will be greater in individuals high in state anxiety and low in DWMc, but where state anxiety is high and DWMc is high, flight error should be reduced.

Hypothesis 2b: State anxiety and the processing and/or storage component of Static working memory capacity (SWMc) interact such that flight error will be greater in individuals high in state anxiety and low in SWMc, but where state anxiety is high and SWMc is high, flight error should be reduced.

4.6 Method

The study was administered after being granted ethics approval by the Macquarie University Ethics Review Committee (Human Research), Ethics Approval Reference: 5201200229.

4.6.1 Participants

Participants were 82 self-selected undergraduate students between 18 and 29 years of age (M = 19.54, SD = 2.40) in the first year psychology subject pool at Macquarie University. Of the 82 participants recruited, 8 were not retained in the final analysis (3 participants who failed to maintain 85% accuracy on the DWMc task and 5 participants who had missing data due to equipment malfunction). Males (44.6%) and females (55.4%) were almost equally represented.

4.6.2 Design

A cross sectional between-group correlational design was used to explore the relationships between threat-based cognitions (i.e., anxiety), working memory capacity, and flight error. Specifically, the study investigated the paths illustrated in Figure 4.1, which correspond to a temporal order as indicated in hypotheses 1-2. The design therefore precluded the use of a cross-over design whereby trial efficiencies might be gained by controlling for learning effects. Instead, a cross-sectional design was favoured due to the concurrent or 'dual nature' of the divided attention task.

4.6.3 Apparatus

A RedBird FMX Flight Simulator was used to model a Cessna 172 single engine aircraft. It is a certified training simulator which features an electronic motion platform, fully enclosed cockpit with a simplified instrument panel, +200° wrap-around visuals, and an ergonomically correct design.

4.6.4 Materials and Procedure

Each participant was tested individually in a single session for approximately 1-1.5 hours, a time that included training in the flight simulator, as well post-experimental interviews. Of the 74 participants, none declined or were deemed to be ineligible to participate, and all gave written, informed consent (reproduced in Appendix 1).

4.6.4.1 Pre-flight Task (Static WMc; SWMc)

Participants were seated approximately 24 in. in front of a 13 in. monitor (MacBook Pro, Mac OS X) and individually administered the operation span (*O*span; see Appendix 2 for task instruction). Administered by the experimenter, the *O*span requires the participant to solve a series of math operations while attempting to recall a set of unrelated words. Participants are presented with one math operation-word string at a time, centred on computer monitor in 20-point font using PowerPoint Software. For each trial, the participant is required to read the equation aloud, indicate its veracity (i.e., Yes or No), and then say aloud a word for later recall. In total, sets of 2 to 5 problems are presented (three trials of each set size; 12 trials in all) before a recall cue '(???)' prompts the participant to write down each word from the preceding set in correct serial order. An example two-item set might read:

Is (8/2) - 1 = 1 ? DOG
Is (6x1) + 3 = 8 ? SNOW
???

Values on the processing component (correctly judged operations) were scored dichotomously (0 = 'incorrect' and 1 = 'perfect score'). In contrast, values on the storage component—correctly recalled words—ranged on a *continuum* from 0.0 ('no recall') to 1.0 ('perfect recall') and were scored according to Conway et al.'s (2005) 'partial-credit unit' procedure (p.775). Thus, this procedure may provide insight into the WMc of an individual and may provide a means to assess WMc (or WMc limitations) either on a dichotomy (processing component) or on continuum (storage component), expressed as a mean proportion of elements within an item set (see Appendix 3 for a brief discussion on scoring complex span tasks; but see also Conway et al., 2005).

4.6.4.2 Flight Training (Pre-flight Competence)

Flight training began with an instruction, telling the participant how to operate the cirrus yoke and how to read certain instrument dials: Vertical Speed Indicator (VSI) when ascending or descending, and the altitude indicator (gyro horizon) when banking. The sequence of tasks for all participants was to: (1) start flight at 5,000 feet (1524 m), maintaining a straight and level course (90-seconds); (2) turn left, maintaining a constant 20° angle of bank (90-seconds); (3) exit turn, re-establishing a straight and level course (30-seconds); and (4) descend, maintaining a rate of descent of -500 feet per minute (fpm) (90-seconds) on the VSI. Tasks 1, 2, and 3 required the aircraft to be in balance at all times (attitude indicator: 0 fpm) with the VSI on 0.

4.6.4.3 Divided Attention Task (Dynamic WMc; DWMc)

The divided attention task was adapted in accordance with Baddeley et al.'s (1985) operation of the central executive. In brief, the task requires the participant to periodically perform a memory-span task while undertaking a primary flight task. When combined with the flying task, the span task is thought to place further limits or constraints on the cognitive capacity of the subject (see Appendix 4).

(i) Memory-Span Task (Alm and Nilsson, 1994)

The memory-span task involves two concurrent activities, namely the processing of sentences (i.e., judging of veracity) and the storage (i.e., rehearsal) of unrelated words. In the first stage, participants are presented with eight blocks of five sentences (40 in all), some of which are meaningful, of the type "Slippers are sold in pairs", and nonsensical, of the type "Thermometers tell the time". In the second stage, participants are required to recall the last word of each sentence (Baddeley et al. 1985; cf. Radeborg, Briem, & Hedman, 1999).

For each block, sentences are presented as a pre-recording, read at a rate of approximately 1.5 words/s, and spaced apart with 4 seconds of silence. Immediately after judging the correctness of the fifth sentence, a tone signalled a 20 second period of silence during which the participant was to attempt to recall in serial order the last word of each sentence. Scores were calculated as previously described in the SWMc task.

(ii) Primary Flight Task

The primary flight task required the participant to maintain a rate of descent of 500 fpm while keeping the altitude indicator at 0°. Specifications of each simulated flight were pre-set at a flight level of 5,000 feet in a managed descent mode (vertical speed indicator: 500 fpm), at 80 knots with a bearing of 7 nautical miles toward a runway. Conditions were set to mimic the net effect of mild to moderate turbulence, and the visibility was similar to a clear summer day with a visibility of approximately 5 mile (8.047 kilometres).

The raw flight data was transformed to produce a real-time metric, where average within-subject error was computed as 'rate of descent' (fpm). First, a raw error score for rate of descent was computed by subtracting the desired score from the observed score (¼ second intervals). For instance, if the desired rate of descent were 500 fpm, then 500 fpm would be subtracted from the observed rate of descent. The absolute values of these error scores (i.e., greater negative scores and greater positive scores) were then taken to reflect deviance from the desired score. Average within-subject error for rate of descent was calculated by computing the mean of these absolute error scores: (i) across training tasks 1-4 [representative of 'pre-flight competence']; and (ii) across the primary flight task [representative of 'flight error'], where higher scores indicated greater deviation from the nominal flight path.

Finally, it was anticipated that confounding factors, such as variations in adapting to aircraft behaviour and response to control inputs and/or fatigue might reduce the integrity of the flight data. Thus the first and last 30 seconds (6.25%) of data were discarded and the remaining cases computed to form a score for each individual (for each parameter, 2 in all). That is, if the flight task took 480 seconds (as in the primary flight task), then 1920 data points were collected and the first and last 120 cases excluded.

4.6.4.4 Post Flight Task

Upon finishing the divided attention task, participants were invited to complete Form Y (Y-1) of the State Trait Anxiety Inventory (STAI-S; Spielberger, 1983). This subscale consists of 20 statements that ask the respondent to evaluate how they feel at a given moment. Respondents rate these statements (e.g., "I am jittery") with reference to the four following anchors: (1) almost never; (2) sometimes; (3) often; and (4) almost always. Total scores range from 20-80 and are calculated by summing the scores for each item (noting reverse scored items) where higher scores indicate greater anxiety (Spielberger et al., 1970). Consistent with previous studies (see, Spielberg 1972), the Y-1 subscale exhibited good internal consistency with coefficient alpha of .86.

Finally, a post-experimental interview collected participants' thoughts evoked during the divided attention task**,** as well as comments on their level of motivation to complete the task and general simulation experience, "Have you ever (currently or previously) regularly played simulation games?" Simulation experience was therefore measured as a dichotomy, with those who regularly played simulation games receiving a score of 1, and all others a 0. See Appendix 5 for interview questions.

4.7 Statistical Procedure

This study tested a number of hypotheses within the framework set out in Figure 4.1. To address hypotheses 1, 1a, and 1b, a hierarchical linear regression was computed entering simulation experience in Step 1, followed by pre-flight competence and state anxiety in Steps 2 and 3 respectively. The processing and storage components of WMc were then entered in Step 4: DWMc processing and DWMc storage for hypothesis 1a and SWMc processing and SWMc storage for hypothesis 1b. Further regression analyses to test for interaction effects were computed at $p < 0.05$.

The SPSS software package was used for all data analysis, with the resulting scores for state anxiety, pre-flight competence and flight error being divided by 10 as a simple scaling procedure. Finally, both pre-flight competence and flight error were positively skewed, and so the natural log was performed to gain a near-normal distribution for the actual analysis. Although the skewed data translates into small number of errors, the results of various simulation studies show that skewed data can often occur due to lower or upper bounds on the flight data (see Meghea, et al., 2009).

4.8 Results

4.8.1 Issues Concerning Data Integrity

Prior to analysis, the distributions of all variables were inspected for deviations from normality with respect to either kurtosis or skewness. All data were within acceptable limits defining normality, where the absolute value of skewness ranged from 0.21 to 0.70, and kurtosis from 0.09 to 1.55 (i.e., skewness < 2 and kurtosis < 4; see Kline, 1998). In addition, two *post-hoc* diagnostic tests were also performed; Cook's D statistic (Stevens, 2012), a global measure of case *i's effect* on overall fit and DFBETA, a measure of influence on the estimate of a regression coefficient, beta. Importantly, no Cook's D scores were > 1 nor any DFBETA's >± 1.

4.8.1 Part 1: To What Extent are Individual Differences in Complex Cognition ('Flight Error') Domain-General or Domain-Specific? Tests of hypotheses 1, 1a, and 1b

The correlation matrix is shown in Table 4.1, with their corresponding means, standard deviations, and inter-correlations. As shown, the intercorrelations between the WMc variables ranged from .11 to .72. In general, these correlations indicate that although the WMc variables are somewhat related; they are conceptually distinct and so further merit being independently investigated. See Appendices 5 and 6 to review relevant scatterplots and/or boxplots for the study variables.

Table 4.1
Correlation Matrix, Means, and Standard Deviations

Variable	*M*	*SD*	1	2	3	4	5	6	7	8
1. Simulation Experience	.54	.50								
2. Pre-flight Competence	1.37	.14	.14							
3. State Anxiety	3.56	.75	.36*	.19						
4. DWMc Processing	.58	.49	-.17	-.15	-.46**					
5. DWMc Storage	.65	.15	-.35**	-.22*	-.48**	.29*				
6. SWMc Processing	.66	.47	-.14	-.19	-.17	.32**	.21			
7. SWMc Storage	.75	.13	-.31**	-.12	.36**	.12	.72**	.11		
8. Flight Error	2.07	.24	.27*	.29**	.52**	-.32**	-.55**	-.18	-.43**	

Note. **p < .01*p < .05; DWMc = Dynamic Working Memory Capacity; SWMc = Static Working Memory Capacity

4.8.1.1 Hypothesis 1a

In Step 1, there was a significant effect of simulation experience on flight error. Similarly, the addition of pre-flight competence in Step 2 and state anxiety in Step 3, were shown to yield significant effects on flight error. However, in Step 4, DWMc storage (B = -.36, t = -3.27, p = .002) but not DWMc processing (B = -.06, t = -0.57, p = .566) was found to affect flight error. Notably, the significant paths from simulation experience (from B = .27 to B = .04) and pre-flight competence (from B = .25 to B = .15) to flight error were reduced to non-significant after variance associated with the DWMc measures—processing and storage—had been accounted for (see Table 4.2).

Table 4.2
Hierarchical Results for DWMc on Flight Error Controlling for Pre-existing Ability Variables

Predictors	R^2	ΔR^2	F	B	T	Sig(p)
Step 1	$.06^{*}$					
Simulation Experience				.27	2.38	.02
Step 2	$.11^{*}$	.06	5.72			
Pre-flight Competence				.25	2.32	.02
Step 3	$.28^{**}$	.16	10.81			
State Anxiety				.45	4.12	<.001
Step 4	$.36^{**}$	.08	9.64			
DWMc Processing				-.06	-.57	
DWMc Storage				-.36	-3.27	.002

Note. *$**p < .025*p < .05$; SWMc = Dynamic Working Memory Capacity*

4.8.1.2 Hypothesis 1b

The results did not change appreciably when statistical analyses were rerun using SWMc measures in Step 4. However, it is worth noting that that the proportion of explained variance was essentially halved when compared with DWMc measures (from $\Delta R^2 = .08$ to $\Delta R^2 = .04$; see Table 4.2 & Table 4.3).

Table 4.3
Hierarchical Results for SWMc on Flight Error Controlling for Pre-existing Ability Variables

Predictors	R^2	ΔR^2	F	B	T	Sig(p)
Step 1	$.06^{*}$					
Simulation Experience				.27	2.38	.02
Step 2	$.11^{*}$	.06	5.72			
Flight Competence				.25	2.32	.02
Step 3	$.28^{**}$	.16	10.81			
State Anxiety				.45	4.12	<.001
Step 4	$.32^{**}$	.04	8.19			
SWMc Processing				-.05	-.50	
SWMc Storage				-.26	-2.47	.02

Note. *$**p < .025*p < .05$; SWMc = Static Working Memory Capacity*

Overall, the results support Hypothesis 1, suggesting that higher scores on basic abilities, such as WMc (the storage component, specifically), add to the prediction of flight error, and this is over and above pre-existing ability. In sum, the results support

Hypothesis 1a, with the distinction that associations between WMc storage and flight error are strongest for dynamic than for static measures of WMc. More specifically, the results suggest that high (but not low) WMc individuals should perform better under inference-rich conditions due to their better ability to allocate attention in a more coherent and goal-oriented way.

4.8.2 Part 2: To What Extent are Individual Differences in WM (as a fixed capacity) Useful for Covering or Limiting the Stress Response? Tests of hypotheses 2, 2a, and 2b

To address hypothesis 2, a backward elimination procedure was first undertaken on the study variables to select major predicting factors. As shown below, after taking into account state anxiety and DWMc storage (Table 4.4) no other variables reached significance in the reduced model.

Table 4.4
Summary Findings for Flight Error Regressed on Study Variables, Including DMWc Measures

	Univariate Model				Mulitvariate Model				Reduced Model			
Variable	B	SE	Β	Sig(p)	B	SE	β	Sig(p)	B	SE	Β	Sig(p)
Simulation Experience	.13	.05	.27	.020	.01	.05	.01	.968	-	-	-	-
Pre-flight Competence	.49	.19	.29	.011	.24	.16	.14	.135	-	-	-	-
State Anxiety	.17	.03	.52	< .001	.10	.04	.29	.017	.11	.04	.33	.003
DWMc [i] Processing	-.16	.05	-.32	.005	-.03	.05	-.06	.566	-	-	-	-
DWMc Storage	-.91	.16	-.55	< .001	-.59	.18	-.36	.002	-.64	.17	-.39	<. .001

Note. [i] DWMc = Dynamic Working Memory capacity

The same backward procedure was re-run again, except this time with measures of SWMc. The analysis was therefore computed for several of the measures for which the raw data were available and the results mirrored those obtained from the more dynamic measures of WMc (see Table 4.4). Indeed, as can be see in Table 4.5, after taking into account state anxiety and SWMc storage (but not SWMc processing) no other variables reached significance in the reduced model.

Table 4.5
Summary Findings for Flight Error Regressed on Study Variables, Including SWMc Measures

	Univariate Model				Mulitvariate Model				Reduced Model			
Variable	B	SE	Β	Sig(p)	B	SE	β	Sig(p)	B	SE	Β	Sig(p)
Simulation Experience	.13	.05	.27	.020	.02	.05	.02	.874	-	-	-	-
Pre-flight Competence	.49	.19	.29	.011	.29	.16	.17	.081	-	-	-	-
State Anxiety	.17	.03	.52	< .001	.12	.04	.37	.001	.14	.03	.32	<. .001
SWMc [i] Processing	-.09	.06	-.18	.115	-.03	.05	-.05	.612	-	-	-	-
SWMc Storage	-.79	.19	-.43	< .001	-.48	.19	-.26	.018	-.59	.17	-.27	.009

Note. [i] SWMc = Static Working Memory capacity

A series of regression analyses were, therefore, conducted to test for interaction effects between state anxiety, WMc storage and flight error.

4.8.2.1 Hypothesis 2a

For the divided attention task, results revealed significant main effects of state anxiety and DWMc storage, as well as a significant state anxiety by DWMc storage interaction, F (3,70) = 17.93, p = .024), adding a further 5% explained variance to the model ($\Delta R^2 = 0.05$, See Table 4.6).

Table 4.6
Hierarchical Regression Results for State Anxiety with DWMc Storage on Flight Error

Predictors	R^2	ΔR^2	F	B	T	Sig(p)
Step 1	$.36^{**}$					
State Anxiety				.33	3.13	.003
DWMc Storage				-.27	-3.70	<.001
Step 2	$.41^{**}$	.05	17.93^{**}			
State Anxiety				.40	2.90	.005
DWMc Storage				-.36	-3.56	.001
State Anxiety by DWMc Storage				-.21	-2.31	.024

Note. $^{**}p < .025$ $^{*}p < .05$; DWMc = Dynamic Working Memory Capacity. R^2, total explained variance; ΔR^2, change in explained variance by step; change in F-ratio by step; B, unstandardised regression coefficient

4.8.2.2 Hypothesis 2b

For the experimenter-paced *O*span task, although results revealed significant main effects of state anxiety and SWMc storage, the addition of the interaction term made no further contribution to the model (p > .05, see Table 4.7).

Table 4.7
Hierarchical Regression Results for State Anxiety with SWMc Storage on Flight Error

Predictors	R^2	ΔR^2	F	B	T	Sig(p)
Step 1	$.32^{**}$					
State Anxiety				.42	4.08	<.001
SWMc Storage				-.29	-2.67	.009
Step 2	$.34^{**}$	.02	13.24^{**}			
State Anxiety				.40	3.98	< .001
SWMc Storage				-.26	-2.61	.011
State Anxiety by SWMc Storage				-.15	-1.55	.125

Note. $^{**}p < .025^{*}p < .05$; SWMc = Static Working Memory Capacity. R^2, total explained variance; ΔR^2, change in explained variance by step; change in F-ratio by step; B, unstandardised regression coefficient

To better understand and simplify the interaction, the study further modelled the DWMc storage-error relationship at different levels of anxiety (low and high; holding state anxiety constant at the 33^{rd} and 66^{th} percentile). Effort was made to probe the significant interaction (Table 4.6) by undertaking a simple slopes analysis. The study found a significant negative relationship between DWMc storage and flight error in the low anxious group (B = -.27), and a significant negative relationship between DWMc storage and flight error in the high anxious group (B = -.34). For those in the high group, the effect size was approximately 22% stronger than for those in the low group (B = -.34 and B = -.27, respectively). This was consistent with post-experimental interviews, where those with lower DWMc storage frequently cited the task as ‘stressful and/or difficult’. In contrast, those with greater DWMc storage frequently cited the task as ‘challenging, novel, and/ or demanding’ (see Appendix 8 for a frequency table of descriptive words relating the divided attention task for those with low WMc (Table 14.1) and high WMc (Table 14.2)).

Overall, the results support Hypothesis 2. Indeed the study found that for participants with high anxiety, increases in DWMc were related to less flight error. For those low in DWMc, however, this pattern of results was reversed; decreases in DWMc (i.e., low DWMc) were linearly associated with greater degradations to flight error.

4.9 Discussion

To restate, the theoretical aims addressed in this research were twofold: first, to test the effect of administration method on the predictive utility of a commonly used updating task, the WM task, and second, to examine the locus of the varied ability to satisfy the *WM* demands of this task. With respect to the first aim, although primary- and secondary administered tests of WM were equally useful and demonstrated low-to-moderate correlations with flight error, the additional stress (i.e., 'cognitive load') when WM was administered as a secondary task improved correlations with flight error. With respect to the second aim, WM (as a fixed capacity) was found to add to the prediction of flight error, and this was over and above measures of pre-existing ability (i.e., simulation experience and pre-flight competence). The present findings are therefore broadly consistent with Attentional Control Theory and demonstrate that WMc may be useful in limiting the stress effect on performance (Eysenck & Derakshan, 2011).

4.9.1 Investigating the First Aim: To What Extent Does Stress Influence the Updating Function of the Central Executive?

The first aim of this study was to test the effect of administration method on the predictive utility of a commonly used updating task, the WM task. The results obtained here may be interpreted as being in accordance with ACT, assuming that the addition of threat-based cognitions (whether psychological or physiological) added to the overall limits on the central executive (of which WM is a part), with the consequence that even a slight increase in constraints (or demands) would have a differential effect on low-and-high anxious individuals.

Although it could be argued that WM tasks are not directly concerned with attentional control, this conclusion is more difficult to accept if and when stress is involved (Eysenck et al., 2007). In fact, some researchers have speculated that, in the absence of threat-based cognitions, updating tasks are more similar to tests of so-called STM (Bailey, 2012). In this view, both tests of WM should emerge as rather weak correlates of flight error, yet the -.43 (SWMc) and -.55 (DWMc) correlations run counter to this expectation. How should these correlations be accounted for?

Eysenck et al.'s (2007) Attentional Control Theory leads to the prediction that anxiety impairs the "updating function *only* under stressful conditions" (p. 367). If high anxious individuals are already characterised by a restricted WM capacity, then the consumption of a further fixed capacity, required in the face of threat-based cognitions (i.e., stress), should reduce the functional capacity of the anxious individual. With respect to the experimenter-paced *O*span task, i.e., SWMc variable, there was of course the stress of the experimenter and both a definite time pressure and clear expectation that a series of items should be recalled. Hence, it may be that the experimenter-paced context—that is, the *loss of control,* and consequently, the added psychological stress on the central executive—that provides some explanation for the significant correlation between SWMc and flight error.

Perhaps more striking, however, were the results obtained when the WM task was administered as a secondary task to the primary flight task. It should be noted that the flight task required a fair amount of attentional control, since the overall weather was rather turbulent, and, even if 'secondary WM task' was easier than 'primary flight task' or vice versa, the emergent consequence of combining the two tasks required, at least to some extent, the engagement of attentional control. Indeed, since ‘the aircraft’ responded slowly to movements of the yolk during the divided attention task (see Appendix 4, lag emphasised in task instruction), the participant not only had to anticipate the programmed clear air turbulence, but also, at the same time, keep the movements of the yolk to a minimum. Thus, it could be assumed that the divided attention task not only placed considerable limits on the central executive but also involved a degree of physiological stress; an assumption which will be tested in Study 2. Indeed, this may explain why the explained variance for DWMc was larger than that of the SWMc variable (DWMc R^2 = .08 and SWMc R^2 = .04).

It follows that for researchers interested in testing hypotheses about immediate memory mechanisms underlying executive attention and cognitive control, a span task designed to impose substantial limits on the central executive is most ideal (Eysenck & Derakshan, 2011). Specifically, the results imply that researchers’ proposing to use stress-inducing protocols, in an attempt to draw out individual differences in threat-based cognitions, are likely to be facilitated by the use of protocols that more strongly emphasise a physiological (and not psychological) effect.

4.9.2 Investigating the Second Aim: What is the Locus of Varied Ability to Satisfy the Working Memory Demands of a Complex Cognitive Task?

The second aim was to explore the components of WM, in the interest of further understanding what the task actually measures: is it, as Sub et al. (2002) notes, the *“storage capacity, processing capacity, the combination of both”* (pp. 285–286, 2002) or indeed “*something beyond storage and processing*” (p. 286). Indeed, given that the WM tasks employed in the present research included both semantic processing (i.e., correctly judged operations/sentences), as well as rehearsal processes (i.e., correctly remembered words), they should at least theoretically engage mechanisms underlying executive attention.

Turning first to the components that make up or comprise the WM task. If, as was previously proposed, the capacity of WM is the ability to process and store information, then both indices should prove useful when predicting flight error. Yet, contrary to expectation, the processing component of the task did not yield any unique variance. Two reasons may account this.

First, the processing component is thought to be of less difficulty in terms of WM load, and therefore could be expected place relatively minor constraints on the central executive. Second, and consistent with correlational evidence, the processing accuracy was close to ceiling and emphasised in task instruction (e.g., 85%). Consistent with Conway et al. (2005) and for the reasons previously described, the obtained results provide some support for the common procedure of not reporting the processing component of WMc. While the present findings contest the predictive utility of the processing component of WMc, they by no means reject its utility as a limiting secondary task. Indeed, the processing component is not only integral to the design of the WM task, but also essential in drawing out individual difference characteristics in complex cognition.

Turning to the issue of whether WM tasks reflect something *beyond* storage and processing (Sub et al., 2002), the question may asked, to what extent are individual differences in complex cognition domain-general or domain-specific. Or, more specifically, is the importance of WM (as a fixed capacity) such that it discounts the influence (or unique variance) of other variables, such as pre-existing ability?

4.9.2.1 To What Extent are Individual Differences in Complex Cognition Domain-General (WM as Fixed Capacity) or a Domain-Specific (WM as an Acquired Skill)?

To establish whether fixed capacity (WMc) and pre-existing ability (a proxy for

LTWM skill) are distinct constructs, the relative correlations between the two variables were first reviewed. If individual difference characteristics in in the WMc mechanism reflect differences in pre-existing ability or vice versa, then high correlations should have emerged. Importantly, non-significant and *low* correlations were observed.

Consistent with hypothesis 1, the fixed capacity mechanism was shown to play a chief role in flight error. Two findings were observed. First, there was the observation that WMc (specifically, the storage component) predicted variance in flight error over and above measures of pre-existing ability (simulation experience and pre-flight competence); and second, there was the observation that, in the final model, measures of pre-existing ability dropped out as insignificant. Taken together, these observations provide support for the *domain-general account* (Conway et al., 2005) and other structural (e.g., Baddeley, 1986) and functional (e.g., Nairne, 2002) models of attentional control.

Thus, given that the study identified the domain-general account (WM as a fixed capacity) to be an independent predictor of complex cognition, there is clearly a need for further consideration of the role it may play in anxious individuals, especially those of whom are motivated to perform well. Thus, a final question addressed is whether WM (as fixed capacity) is useful for covering and/or limiting the stress response. In other words, can WMc ameliorate the aversive affects of anxiety?

4.9.2.2 To What Extent are Individual Differences in WM (as a fixed capacity) Useful for Covering or Limiting the Stress Response?

The present study tested the specific hypothesis that WMc and state anxiety would interact to explain variance in a complex cognitive environment (i.e. simulated flight). Specifically, the obtained results showed that for individuals with low DWMc, increases in state anxiety were related to increases in flight error, whereas for those with high DWMc, the pattern of results was reversed. Two aspects must be considered vis-à-vis the theoretical and methodological significance of the present findings. The discussion begins by investigating two moot ideas, specifically, how well the results harmonise with (1) Eysenck et al.'s (2007) Attentional Control Theory and (2) Baddeley's (1986, 2001) theory of WM.

First, the results point to the novel finding that participants' with both high DWMc and high anxiety showed better performance than those with low DWMc. The results accord with reports in the self-help and WM area that threat-based cognitions involve increased motivation to minimise—via auxiliary processing resources—the aversive anxiety state (Fernandez-Castillo & Gutierrez-Rojas, 2009). Indeed, an often-cited limitation of most immediate-memory frameworks, if not all, is that they fail to fully account for anxious persons' ability to compensate for impaired processing, and so non-existent effects of threat-based cognitions on performance are sometimes observed (Eysenck et al., 2007). Importantly, the results extend this proposition to suggest that this utility (or advantage) is only possible if the individual is first equipped with the resources or cognitive capacity to offset the anxious state.

As was previously mentioned, attentional control theory is based on Baddeley's tripartite model of WM, since expanded into a four-component model (Baddeley, 1986; 2001). Since the current study employed a dual-task paradigm, in which two tasks were performed concurrently, namely a primary flight task (i.e., *ongoing* visual tracking task; visuospatial sketchpad) and secondary DWMc task (i.e., verbal WM sentence-span; phonological loop), it may be reasoned that both tasks involved distinct slave systems, and therefore did not contend for immediate-memory storage. It follows that the present findings may be explained as reflecting attentional control limitations, since this component of WM (i.e., central executive) would be required to coordinate processing on the two tasks in addition to the demands of each task separately, as well as for directing the flight task.

Broadly, the cognitive by threat-based cognition interaction finding supports Eysenck and Derakshan (2011) assertion that anxious individuals show impaired performance in dual-task situations, especially those in which concurrent demands are both complex and attentionally demanding. More specifically, the overall pattern of findings suggest that given a high WMc, higher levels of threat-based cognitions (i.e., anxiety) may be associated with increased motivation to reduce the aversive state (i.e., avoid negative evaluation). It follows that to meet the standard set by with low anxious individuals, high anxious participants' may, given sufficient resources, require extra effort (via motivation) to complete the task.

4.9.6 Limitations and Directions for Future Work

Several limitations are inherent in the current research and warrant consideration when interpreting the findings. Firstly, the findings implicitly assume the presence of physiological stress. Since the present research employed a cross-sectional design, the findings are therefore of general relevance to ACT. In an attempt to explain the findings, a divided attention task ('dual-task paradigm') was employed in which task loads were generally very taxing of the participants' attention. Such demands are consistent with what Shallice and Burgess (1993: 174) proposed as conditions requiring involvement of the supervisory attentional system (counterpart of the central executive proposed by Baddeley & Hitch, 1974, as cited by Radeborg, Briem, & Hedman, 1999), which were (i) decision-making; (ii) error correction; (iii) responses to novel action sequences; (iv) actions in technically difficult situations; and (v) overcoming a strong automatic response. Importantly, these conditions correspond well to what was required here for the DWMc task, which in turn may explain why it was a more sensitive measure than the experimenter-paced *Ospan task* (i.e., SWMc variable).

Second, with regard to state individual difference variables, the use of self-reported data relates to the perception of experienced anxiety and this may not account for the dynamic nature of physiological changes (had they occurred). While the emphasis in the current study has been on negative mood states as a personality dimension, typically assessed by self-report, it is recommend that other physiological markers be measured, including those that capture heart rate variation and electrodermal activity.

In conclusion, the data provides a clear suggestion of the role WMc has in successful flight performance, at least at the level of training. In addition, the present findings extend previous research to highlight WMc as an underpinning mechanism in which to explain the effect of anxiety on complex cognition. While individuals ability to control attention will result primarily from the constraints of the situation, among those who are anxious, considerations of available ‘capacity’ might assist in the identification of individuals’ who will better perform under high cognitive loads. It follows that low WMc acts much like a ‘secondary task’ in dual task paradigms by preempting the limited attentional resources of WM. That is, when task demands increase to become excessive, those individuals with lesser capacity are predicted to have already cluttered their cognitive workspace, and this is before they have factored in the negative effect of threat-based cognitions. However, where auxiliary processing resources are available, potential performance improvement in ‘high anxiety, high WMc’ individuals, is likely explained by an increased motivation (i.e., effort) to minimise the aversive state (Eysenck et al., 2007). To address this proposition more clearly, cardiovascular measures of task engagement (or indeed motivation) should be measured in future research (Schwerdtfeger & Kohlmann, 2004).

5 Chapter Five: Study Two

5.1 Introduction

Human factors and cognitive (HF/C) science continues to demonstrate that unpleasant psychophysiological states (autonomic arousal), narrows an individual's attention and decreases their cognitive workspace (i.e., WM, for review, see Deraskshan & Eysenck, 2009). Threat-based cognitions (i.e., manifest anxiety), in particular, have become a critical area of study both for research investigating human-machine interaction and for practical purposes in understanding the psychological and concomitant physiological responses to stress (Huttunen et al., 2010).

5.2 Self-Report and Physiological Measures of Arousal (or Stress per se)

Arousal measures may be as crude as observing whether or not a person panics, or as refined as the tracking of ocular behaviour or the monitoring of electrical activity (e.g., the electroencephalogram; Davis, Daluwatte, Colona, & Yao, 2014; and Dussault, Jouanin, Philippe, & Guezennec, 2005). However, one particular aspect of arousal that has received considerable attention from the HF/C field and researchers alike is that of the "synthetic evaluation method"—namely, the combined *use* of both self-report and physiological evaluation methods (Zhang, Wanyan, Zhuang, & Wu, 2014, p. 110).

5.2.1 Self-Report Evaluation

One of the most commonly used self-report measures of autonomic arousal is the Spielberger's State–Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), a well-validated inventory that provides measures of both state and trait anxiety. State anxiety (STAI-S), in particular, refers to a transient emotional state and may be defined as a "state in which an individual is unable to instigate a clear pattern of behaviour to remove or alter the event … that is threatening an existing goal"

Power & Dalgleish 1997, pp. 206-207). At a personal or academic level, STAI-S has been implicated in research that has helped delineate the various threat-based reactions to stressors in the human (e.g., Amir, Weber, Beard & Bomyea, 2008), as well as the physiological activation of the autonomic nervous system. Overall, the STAI-S offers excellent psychometric properties, with Cronbach *alpha's* typically in the range of .86 and .95 (Spielberger, 1983), although test-retest correlations are rather low (in the *Manual*'s samples r = .34 - .62).

5.2.2 Physiological Evaluation

Physiological assessment has long been viewed as a relative pure source of data with respect to autonomic arousal (Lehrer et al., 2010). Galvanic skin response (GSR) and heart rate variance (HRV), in particular, are especially useful for operational assessments because they are "relatively inexpensive and simple to acquire and analyse" (p. 14, Singh & Queyam, 2013). Moreover, physiological measures such as GSR and HRV are among the best indices because they capture 'real-time changes' in the operator's ongoing functional state (e.g., Wilson & Russell, 2003a; and Scerbo et al., 2001; but see also Shackman et al., 2006).

5.2.2.1 Galvanic Skin Response

Prominent among the measures used to assess manifest arousal are indices of electrodermal activity (Critchley, 2002). While there are, of course, various techniques by which electrodermal activity can be assessed, the most frequently cited (and often used) are measures of GSR.

In 1965, Katkin conducted one of the earliest comparisons of manifest anxiety and autonomic response to threat-based cognitions. Katkin showed that participants had comparable mean GSR at rest; however, during the experimental period (*threat of shock*), GSR increased under threat, whereas, under non-threat conditions, GSR remained essentially the same. These and similar results (e.g., Christenson, Ferrara, & Kim, 2012) support the hypothesis that GSR increases in response to physiological stress (Civitello et al., 2014; and Peper, et al., 2008).

5.2.2.2 Heart Rate Variability

Parameters of HR rhythm and HRV, measured as R-R intervals, reflect both autonomic modulation and the function of modulatory reflexes necessary for adaptation to various putative stressors (heat and cold, for example). Various changes in heart rate, particularly HRV, have been found to be related to both ‘mentally loading tasks’ and ‘cognitively loading tasks’ (e.g., Van Leijenhorst, Crone, & Van der Molen, 2007), and appear to be sensitive to increases in mental effort (Nagano, 2002). As to their specific sensitivity, Lehrer et al. (2010) found that R-R intervals discriminated high from medium and low load tasks, whereas, Hankins and Wilson, (1998) showed that HRV discriminated medium from low load tasks. Other studies have likewise reported this link, with HRV being described as having a “gradual downward trend” with increasing loads (Wanyan, Zhuang, & Zhang, 2014, p. 113).

Taken together, these studies generally conclude that increasing the limits on an operator’s cognitive workspace (Mehler, Reimer, & Wang, 2011) increases their perception of task difficulty (Boutcher & Boucher, 2006) and, perhaps not surprisingly, decreases their HRV (see Kulmala & Hynynen, 2011, for a review).

5.3 The Present Research

The research developed here represents an extension of the work and findings put forward in Study 1. As such, the focus of the theoretical predictions in this study are the effects of threat-based cognitions—specifically, induced or manifest anxiety—on cognitive processing, in particular those placing substantial constraints on the central executive (Deraskshan & Eysenck, 2009; and Eysneck et al., 2007). The present work makes progress toward three broad research goals.

5.3.1 Research Goals

First, it was important to determine whether the results from the cross-sectional study (Study 1) could be *replicated* using a between-groups design with one group serving as the control (conditions matched to those of Study 1) and the other as the experiment (threat of shock).

Second, an attempt was made to improve the measurement of manifest arousal by measuring both the subjective experience of anxiety (e.g., STAI-S, Spielberger et al., 1983) and, as previously noted, several physiological measures, including GSR (Bakker, Pechenizkiy & Sidorova, 2011) and HRV (Lee & Liu, 2003). Thus, a specific goal was to determine whether electrodermal activity (i.e., GSR) and cardiac data (i.e., HRV) could differentiate between control and experimental groups. Importantly, this 'synthetic evaluation method' fits very neatly within Shackman et al.'s methodological desideratum for studying the effects of anxiety on cognition, namely, that *"the presence of the intended emotions must be adequately verified*" (2006, p. 42).

Third, the design of study 1 was *extended* to manipulate the experience of stress. In Study 1, the requisite task was to periodically perform a WM task while undertaking a primary flight task—namely, maintaining a 'rate of decent' of 500 feet per minute. While the specifications for each flight were set at a level of 5,000 feet, it might be argued that, during sustained operations like cruise mode, workload (Scerbo, 2001) and states of arousal are reduced. In other words, the requisite task (so-called divided attention task) may have seemed onerous, but may not have been so overly demanding as to elicit a 'true' stress response. To address this limitation, the study employed *threat of shock* as a stress inducing protocol (e.g., Bradford, Shapiro, & Curtin, 2013; and Hu, Bauer, Padmala, & Pessoa, 2012). Again, this approach fits neatly within Shackman et al.'s methodological desideratum for studying the effects of anxiety on cognition, namely, that *"lasting affect must actually be elicited"* (2006, p. 42).

5.3.2 Threat of Shock as a Stress Inducing Protocol

When threatened with an unpredictable or aversive event (*threat of shock, in particular*), participants show elevated startle reflex (Grillon, 2008a, 2008b), increased vigilance towards salient stimuli (Cornwell et al., 2007) and impaired WM performance (Erk, Kleczar, & Walter, 2007). Thus, according to Shackman et al. threat of shock—a relatively potent elicitor of threat-based cognitions—should serve as a useful "affect induction procedure" (2006, p. 43). Unlike alterative protocols, such as affective music clips (Schmidt & Trainor, 2001) or affectively laden film clips (Gross & Levenson, 1995), threat of shock is thought produce a relatively pure (and therefore potent) state of anxiety (Shackman et al., 2006). In fact, the authors go so far as to assert that it is rather simple to impose 'threat-induced' anxiety upon cognitive performance without also "introducing a substantial secondary cognitive load" (p. 44).

5.4 Hypotheses: Rationale for the Present Study

Experimentally, exposure to stress provides at least three benefits (Osinsky, Alexander, Gebhardt, & Hennig, 2010). First, exposure to stress evokes a complex behavioural and neuroendocrine response (e.g., Gambarana, 2005), which can mimic symptoms that represent specific human psychiatric disorders (anxiety); second, the experience of stress (when manipulated) carries with it certain properties that reproduce the natural environment, which can make findings more germane to real-world scenarios; and finally, and perhaps of most importance, when controlled within the participant, the experience of stress can be inferred to the manipulation itself. In this context, it was of interest whether the results of Study 1 could be replicated under more stressful conditions—namely, under threat of shock. Thus, the same hypotheses as

Study 1 were tested for Study 2, except that physiological data was used to enhance the generalisability of Study 1 (See Figure 5.1). Specifically, it was predicted that, consistent with cognitive interference theories (e.g., Eysenck et al., 2007), *threat of shock* would have a differential influence on physiological activity—increasing GSR and decreasing HRV.

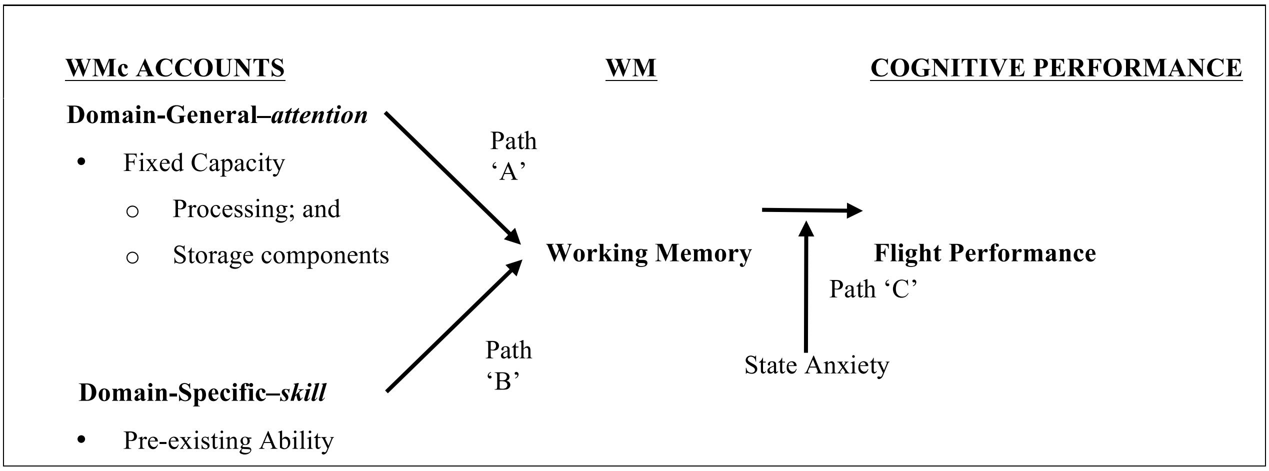

Figure.5.1 An Illustration of the Domain-general Account and Domain-specific Account on Cognitive Performance

Given that this study served as a replication and extension of the first, the same hypotheses were tested:

Hypothesis 1a: Higher scores on the processing and/or storage component of Dynamic working memory capacity will be associated with a decrease in flight error, after controlling for a person's pre-existing ability (i.e., simulation experience, pre-flight competence, and state anxiety).

Hypothesis 2a: State anxiety and the processing and/or storage component of Dynamic working memory capacity (DWMc) interact such that flight error will be greater in individuals high in state anxiety and low in DWMc, but where state anxiety is high and DWMc is high, flight error should be reduced.

5.5 Method

The study was administered after being granted ethics approval by the Macquarie University Ethics Review Committee (Human Research), Ethics Approval Reference: 5201200229.

5.5.1 Participants

132 Macquarie university students (36.5% men, 63.4% women) between the ages of 18 and 25 years (M = 19.18, SD = 1.92) met the eligibility criteria for participation (consent form reproduced in Appendix 9). Exclusion criteria included, persons with pacemakers, diabetes, epilepsy, chronic pain or any other similar or related illnesses. In addition, participants were excluded if they were under the age of 18 or if they met the DSM-IV criteria for generalised anxiety disorder—none did.

5.5.2 Design

The study was a between-subject comparison design and participants were randomly assigned to either a control (neutral instructions as per study 1, n = 65) or experimental condition (instructions to anticipate an electric shock, n = 65). As in the first study, we investigated the paths illustrated in Figure 5.1, which correspond to a temporal order as indicated in hypotheses 1-2.

5.5.2 Apparatus

5.5.3.1 Flight Simulator

A RedBird FMX Flight Simulator was used to model a Cessna 172 single engine aircraft. It is a certified training simulator which features an electronic motion platform, fully enclosed cockpit with a simplified instrument panel, +200° wrap-around visuals, and an ergonomically correct design. Together, these subsystems offer the study participant an impression of real flight.

5.5.3.2 Laboratory Stressor

The stress manipulation was an adapted version of Stapinski's (2008, in press) physical threat task, as used by Abbott and Rapee, (2004) to induce anxiety. The stimulation box, labelled 'SHOCKER', was a rectangular in shape and had two lead 15 x 15 mm stainless steel electrodes attached. A small green light-emitting diode was visible when the stimulation box was in use. Two large, circular dials, adjacent and directly below the small diode, were labelled 'Duration – Seconds' and 'Intensity – mA'. The 'Duration – Seconds' dial (on the left hand side) had 10 levels ranging from 0.1 to 1.0 second. The dial labelled 'Intensity – mA' (on the right hand side) had 11 levels, ranging from .1 to 4 milliamps, with intervals of either .25 or .5 milliamps (see Figure 5.2).

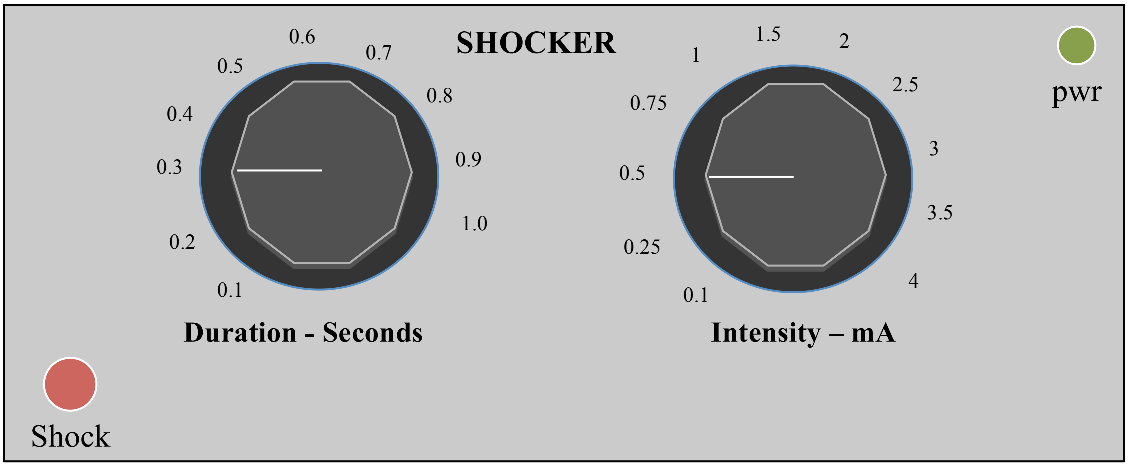

Figure.5.2 Top View of the Stimulation Shock Box

Importantly, shocks were self-administered via a small red button labelled "Shock" and set a duration of .3 of a second. Input leads from the two 15 x 15 mm stainless steel electrodes were attached via shielded wires to the stimulation box.

5.5.3.3 Other Known Stressors

Clearly other known stressors exist in the context of aviation. Aviators are experienced operators who must routinely perform in dynamic (i.e., rapidly changing) multi-task flight environments under conditions of time pressure, uncertainty, and cue ambiguity (Cuevas, 2003). Task performance in such high demand, high cognitive load environments exposes the subject to both psychological stressors (e.g., task overload both high and low; Armentrout et al., 2006, fatigue) as well as environmental stressors (e.g., noise, motion; Wickens, Gordon, & Liu, 1999). In the current design, the REDBIRD flight simulator uses full motion simulation to provide effective motion feedback for yaw, pitch and roll with an actuation mechanism that is rotational via motors and belts. In terms of noise, the cockpit itself is in motion and hence some noise is generated: realistic sound was channelled through a GMA1347 Audio Panel, with the G1000 COM radios operating in the aviation frequency band of 118,000 to 136,990 Megahertz with either 25 kilohertz or 8.33 kilohertz channel spacing producing high levels of continuous noise. Thus, noise level comprised a mixture of random (broadband) and periodic frequencies (the aircraft signature or "whine") and in the case of programed air turbulence and chop; transient high-level noise generated by the programmable crosswind.

5.5.3.4 Instrumentation: Physiological Recording Devices

AD Instruments and a Suunto Ambit2 wristwatch were used to measure GSR and mean HRV, respectively.

5.5.3.4.1 AD Instruments (Galvanic Skin Response)

Electrodermal activity (sweat) was collected via two 15 x 15 mm MLT116F electrodes. These electrodes were connected to a FE116F GSR amplifier, which in turn was connected to a PowerLab data acquisition unit. The MLT116F electrodes could be attached via adhesive collars to the innermost (most proximal) and outermost (most distal) toe of the participants' dominant foot. Two GSR parameters were calculated:

i. Mean GSR; and
ii. Incremental change in GSR (ΔGSR), which was derived by taking the difference

between work and rest rates.

5.5.3.4.2 Suunto Ambit 2 Wrist Watch (Heart Rate Variability)

The current study used a sophisticated version of the Suunto t6, the Suunto Ambit2, a device that houses the same technology, but with additional features (e.g., Barometer, Elevation and GPS). The Suunto Ambit2 system consists of a breast belt that transmits R-R interval values to a wristwatch. Data is then synced to a Macintosh OS X laptop using the manufacture-supplied interface, Movescount, which is then exported into Excel (Microsoft) spreadsheets. The same parameters collected for GSR were also collected for HRV (i.e., R-R wave intervals). [6]

For both GSR and HRV, measures were obtained across three time periods:

T1. Baseline characteristics at rest. For each participant, a resting period—baseline measurement—of at least 5 minutes or longer, if required, was collected from the outset of the experiment.

T2. Flight training, consisting of four phases:

i. Start of flight at 5,000 ft (1524 m) maintaining straight and level course (90-seconds);
ii. Maintaining a constant 20° angle of bank – vertical speed indicator at 0 (90-seconds);
iii. Exiting from a turn accurately – reestablishing level flight (30-seconds); and
iv. Maintaining a rate of descent of 500 Feet Per Min (ft/min), keeping the aircraft in balance at all times (90-seconds); and

T3. Across the divided attention task (i.e., the dual WMc/primary flight task).

5.5.4 Materials and Procedure

Each participant was tested individually in a single session for approximately 1-1.5 hours. Of the 132 participants, *two* were deemed ineligible to participate, and all (*n* = 130) gave written, informed consent. The consent form clearly described the study

[6] A recent paper by Weippert, Kumar, Kreuzfeld, Arndt, and Rieger (2010) compared an ambulatory five-lead electrocardiogram (ECG) system with three commercially available breast belt measuring devices: Polar S810i, Polar S810i and Suunto t6. In terms of R-R interval measures and HRV indices, the study found good agreement between the devices, and this was most true among the Polar and Suunto brands.

procedures (illustrated in Figure 5.3), assured the confidentiality of participation, and stated in bold clear font that they could, “at any time, end their participation” without penalty.

Upon arriving at the laboratory, the participants underwent a semi-structured interview to ensure eligibility. If eligible, participants were given a resting phase of 5 minutes before the first GSR and HRV readings were taken (baseline characteristics). Five minutes later (10 minutes after arrival, or longer if required) participants attended flight training, where they were guided in completing four flight-training tasks (see instructions in Appendix 4). After this point, the procedures differed for the control and experimental groups.

5.5.4.1 Control Group

The experimenter introduced the participant to the stimulation box and reminded them of the exclusion criteria. Once seated, two 15 x 15 mm stainless steel electrodes were attached to the innermost (most proximal) and outermost (most distal) toe of the participants’ non-dominant foot. The participant was then guided in *self-administering* shocks until they reached a level that was “very uncomfortable but not painful” (somewhere from barely perceptible [0.1 milliamps; mA] to a maximum of 4mA).

After completing the stimulation task, the participant was informed that this part of the experiment was finished, and that he or she would receive NO MORE SHOCKS. The participant then went on to complete the divided attention task (instructions reproduced in Appendix 9), which was followed by two post experimental activities, the STAI-S and a post-experimental interview. This was done to match the conditions of Study 1.

5.5.4.2 Experimental Group

The procedures for the stimulation box were identical to those used with the control group except that immediately after the final shock (i.e., what was identified as their pain-threshold), the participant was told that the box would be recalibrated. The experimenter went on to explain that the stimulation box had “two settings”: (i) a self-administer setting, which they had previously used, and (ii) a random pulse setting, which they would experience shortly.

If the participant agreed to continue, the experimenter went on to say that the stimulation (or intensity) would be “increased two levels beyond their identified threshold” and that, although “students do find them to be quite painful,” the shocks “are not physically dangerous”. In this way, there was both a definite loss of control and a clear expectation that a shock could occur.

The participant was then informed that the random shocks would occur throughout the divided attention task and that, although the task would take approximately 7 minutes, they could withdraw from the experiment at any time. After the participant completed the divided attention task, they completed the STAI-S and post-experimental interview.

At the conclusion of the post-experimental interview, the experimenter gave the participant a letter, and it said:

> At this point I would like to provide you with some additional information about the nature of the experiment. This experiment involved DECEPTION. Contrary to what you have already been told, NO ELECTRICAL SHOCKS WERE ADMINISTRERD. The stimulation box was never increased in intensity. In fact, the electrodes, which are attached to your foot, were DISCONNECTED from the stimulation box, and therefore it would have been IMPOSSIBLE to receive a shock. This experiment required the use of deception because we are attempting to study if, and how, students respond to psychological and physiological stress. Importantly, we can compare your results with those who knew they would not be shocked, or, more

specifically, those who were assigned to the control group. In other words, you are the experimental group.

Finally, it is worth noting that the stainless steel electrodes were not removed from the participant's toes, and it was never demonstrated that the electrodes were disconnected from the stimulation box or fake. Thus, from the participant's point of view it was still plausible for the stimulation box to still generate a random shock, and consequently, the effectiveness of the manipulation was entirely dependent on the participant's appraisal in what was said by the experimenter.

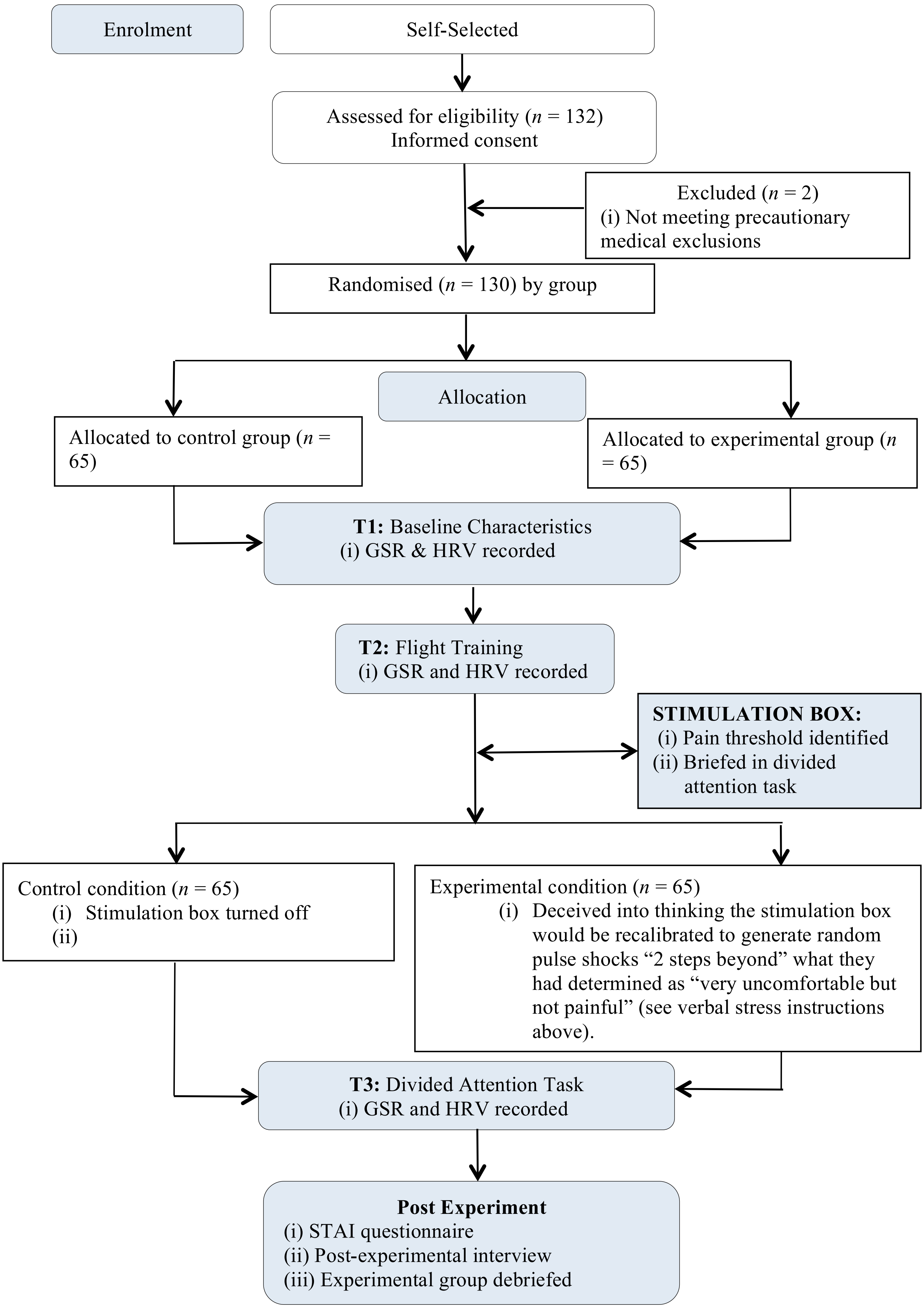

Figure.5.3 Illustration of the Timeline of Events in Study 2

5.5.5 Statistical Procedure

This study tested a number of hypotheses within the framework set out in Figure 5.1. More specifically, the major analyses conducted to test our hypotheses were repeated separately for each group (control and experimental). Statistical procedures were essentially the same as Study 1.

To address hypotheses 1a, a hierarchical linear regression was computed entering simulation experience in Step 1, followed by pre-flight competence and state anxiety in Steps 2 and 3 respectively. The processing and storage components of WMc were then entered in Step 4: DWMc processing and DWMc storage. Backward elimination procedures were conducted with inclusion and exclusion criteria set to .05 and .051 respectively. For the remaining variables, a series of regression analyses were conducted to test for interaction effects of the proposed models using a Bonferroni correction of $p<0.025$ (reset from .05). Finally, as with Study 1, both pre-flight competence and flight error (the dependent variable) were positively skewed, and so the natural log was performed to gain a near-normal distribution for the actual analysis. Data was therefore manipulated prior to analysis, and as with Study 1, outliers were manipulated according to specific guidelines: (1) no more than 5% of cases ($n = 6$) from any one analysis (Cohen & Cohen, 1983); and (2) only cases greater than three standard deviations above or below the mean were revised (cf. Shackman et al., 2006). Thus, following the recommendation of Tabachnick and Fidell (2001), outliers were recoded as one unit greater than the highest non-outlier value.

5.6 Results

This section begins be examining the hypothesis regarding the effects of threat of shock on cognitive processing. In particular, electrodermal activity (i.e., GSR) and cardiac data (i.e., HRV) were examined to determine whether physiological indices could differentiate between control and experimental groups (Goal 1). The section then continues to examine whether the results of the control group provide, if at all, a close replication to the results of study 1 (the second goal; Goal 2), and concludes by testing the same hypotheses again, but for those in the experimental group (Goal 3).

5.6.1 Goal 1: Physiological Differences Between Control and Experimental Groups

Inter-and intra group comparisons of physiological arousal (i.e., potential GSR and HRV differences) were made with independent and paired samples *t* test for group and task contrasts, respectively.

5.6.1.1 Independent Samples t-test (Group Contrasts)

For the GSR data, independent-samples *t*-test performed between the two groups (control and experimental) did not demonstrate any significant difference between baseline characteristics at rest $t(118) = -0.8$, $p = .936$; nor during tests of pre-flight competence $t(118) = -1.29$, $p = .200$; however, did, yield significant differences across the divided attention task $t(118) = -3.68$, $p < .001$ (*M* and *SD* reported in Figure 5.4).

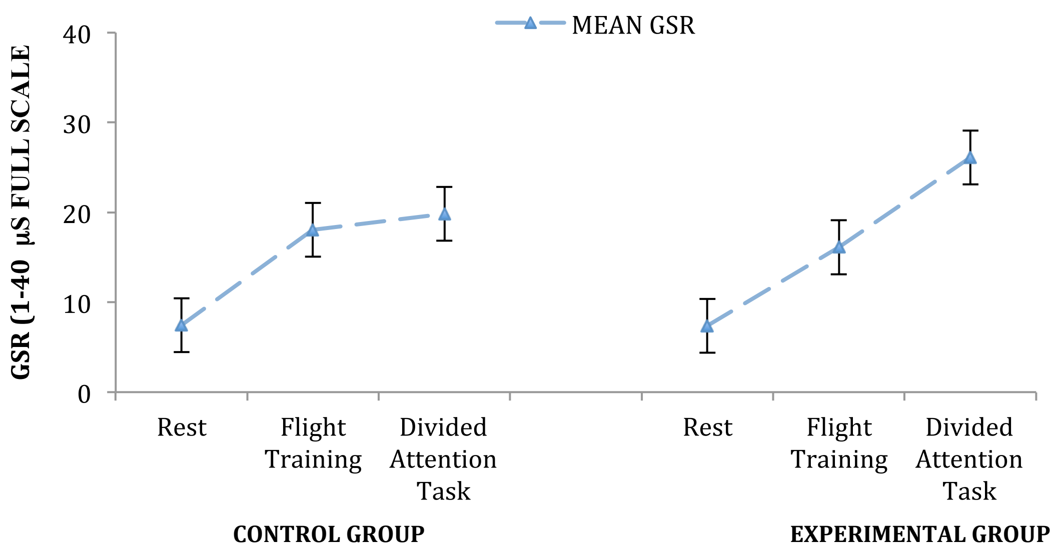

Figure.5.4 An Illustration of GSR Data for Study 2, Means and Standard Deviations Across Three Phases of the Laboratory Session

The HRV data yielded similar approximations, with no differences between baseline characteristics at rest $t(112) = -1.11$, $p = .266$ or pre-flight competence $t(113) = .118$, $p = .906$. By contrast, group differences did emerge for the divided attention task $t(113) = -2.07$, $p = .041$); however, on account of technical errors (incomplete data on 8 R-R series), the data was subsequently dropped (*M* and *SD* reported in Figure 5.5).

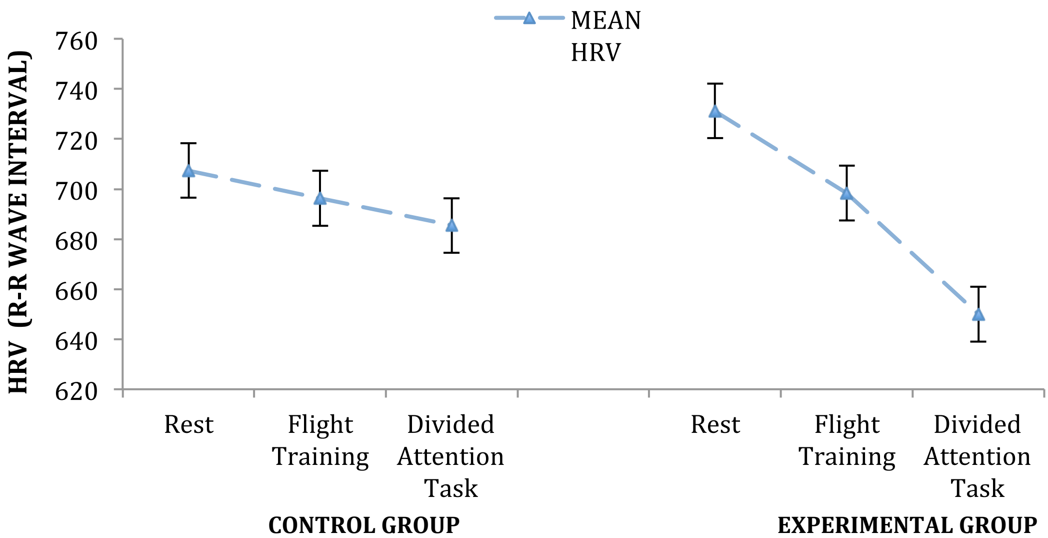

Figure.5.5 An Illustration of HRV Data for Study 2, Means and Standard Deviations Across Three Phases of the Laboratory Session

5.6.1.2 Paired Samples t-test (Task Contrasts)

Intra-group comparisons were performed using paired samples *t* tests for only the GSR data—HRV data were omitted from all subsequent analyses.

5.6.1.2.1 Control Group

A paired samples *t* test comparing GSR levels at rest with GSR levels during tests of pre-flight competence showed a significant increase, $t(61) = -12.16$, $p = < .001$. The same pattern was found when comparing GSR levels during tests of pre-flight competence and GSR levels across the divided attention task, $t(61) = -3.12$, $p = .001$.

5.6.1.2.1 Experimental Group

The same intra-group comparisons were made for the experimental group. A paired samples *t* test comparing GSR levels at rest with GSR levels during flight tests of pre-flight competence showed a significant increase, $t(57) = -12.33$, $p = < .001$, as did a pairwise comparison between GSR levels during tests of pre-flight competence and GSR levels across the divided attention task, $t(56) = -11.61$, $p < .001$. It is worth noting, however, that when compared to the control group, the *t* value was almost 4 times greater in the experimental group (see Figure 5.4).

5.6.2 Goal 2: Replication of Study 1 — Investigating the Control Group

The correlation matrix is shown in Table 5.1, with their corresponding means, standard deviations, and inter-correlations. As shown, the means and standard deviations for the DWMc variables were similar to those reported in the first study (study 1; processing: $M = .58$, $SD = .49$; storage: $M = .65$; $SD = .15$; and for study 2; processing $M = .55$, $SD = .50$; storage: $M = .67$; $SD = .14$. Thus it was found, by experimentation across studies, that participant's performance on the divided attention task remained consistent, and this was for both processing and storage components of the WM task.

Table 5.1
Correlation Matrix, Means, and Standard Deviations

Variable	*M*	*SD*	1	2	3	4	5	6
1. Simulation Experience	.59	.49						
2. Pre-flight Competence	1.45	.14	.20					
3. State Anxiety	3.69	.84	.26*	.19				
4. DWMc Processing	.55	.50	-.05	-.03	-.28*			
5. DWMc Storage	.67	.14	-.34**	-.21*	-.42**	.34*		
6. Flight Error	2.18	.19	.25*	.28**	.47**	-.21*	-.54**	

Note. **p < .01*p < .05; DWMc = Dynamic Working Memory Capacity

5.6.2.1 Test of Hypotheses on the Control Group (Conditions matched to those of Study 1)

5.6.2.1.1 Hypothesis 1a

Hypothesis 1a investigated the extent that individual differences in complex cognition ('flight error') were domain-general or domain-specific. In Step 1, there was a significant effect of experience on flight error. Similarly, the addition of pre-flight competence in Step 2, and state anxiety in Step 3, were shown to yield significant effects on flight error. However, in Step 4, and consistent with Study 1, DWMc storage (B = -.33, t = -2.60, p = .012) but not DWMc processing (B = -.04, t = -0.39, p = .695) was found to affect flight error (see Table 5.2).

Table 5.2
Hierarchical Results for DWMc on Flight Error Controlling for Incoming Ability Variables

Predictors	R^2	ΔR^2	F	B	T	Sig(p)
Step 1	.06*					
Simulation Experience				.26	2.11	.039
Step 2	.10*	.04	4.33			
Pre-flight Competence				.24	1.99	.051
Step 3	.28**	.18	8.80			
State Anxiety				.44	3.45	.001
Step 4	.34**	.6	7.41			
DWMc Processing				-.04	-.39	
DWMc Storage				-.33	-2.60	.012

Note. **p < .025*p < .05; DWMc = Dynamic Working Memory Capacity

5.6.2.1.2 Hypothesis 2a

As in Study 1, all variables that were determined to be confounds (i.e., pre-existing ability variables) or were variables of interest were entered into a multivariable regression model and subsequently removed in a stepwise fashion (i.e., P > 0.51). As can be seen, after taking into account state anxiety and DWMc storage, no other variables reached significance in the reduced model (see Table 5.3).

Table 5.3
Summary Findings for Flight Error Regressed on Study Variables

	Univariate Model				Mulitvariate Model				Reduced Model			
Variable	B	SE	B	Sig(p)	B	SE	β	Sig(p)	B	SE	B	Sig(p)
Simulation Experience	.01	.05	.25	.043	.01	.04	.02	.846	-	-	-	-
Pre-flight Competence	.38	.16	.28	.024	.26	.14	.19	.079	-	-	-	-
State Anxiety	.10	.03	.47	< .001	.07	.03	.31	.012	.07	.03	.29	.013
DWMc [i] Processing	-.09	.04	-.25	.052	-.01	.04	-.04	.695	-	-	-	-
DWMc Storage	-.73	.14	-.54	< .001	-.45	.17	-.33	.012	-.56	.15	-.41	.001

Note. **p < .025*p < .05; DWMc = Dynamic Working Memory Capacity

A further regression was conducted to test for interaction effects between state anxiety, DWMc storage and flight error. As with Study 1, the divided attention task revealed significant main effects of state anxiety and DWMc, as well as a significant state anxiety by DWMc storage interaction term, *F* = [3,57] = 14.30, $p < .001$, adding a further 5% to the model (see Table 5.4).

Table 5.4
Hierarchical Regression Results for State Anxiety with DWMc Storage on Flight Error

Predictors	R^2	ΔR^2	*F*	B	T	Sig(p)
Step 1	.34**					
State Anxiety				.29	2.57	.013
DWMc Storage				-.41	-3.50	.001
Step 2	.39**	.5	14.30**			
State Anxiety				.33	2.98	.004
DWMc Storage				-.36	-3.21	.002
State Anxiety by DWMc Storage				-.25	-2.49	.015

Note. **p < .025*p < .05; DWMc = Dynamic Working Memory Capacity. R^2, total explained variance; ΔR^2, change in explained variance by step; change in F-ratio by step; B, unstandardized regression coefficient; associated t-statistic.

As in Study 1, and to better understand the interaction, the study further modelled the DWMc storage-error relationship at different levels of anxiety (low and high; holding state anxiety constant at the 33*rd* and 66*th* percentile). Again, a significant negative relationship between DWMc storage and flight error in the low anxious group (B = -.32) was observed, and so too was a significant negative relationship between DWMc storage and flight error in the high anxious group (B = -.38). For those in the high group, the effect size was approximately 19% stronger than for those in the low group (from B = -.38 to B = -.32), which was similar in strength to study 1, at 22%.

5.6.3 Goal 3: Extension of Study 1 — Investigating the Experimental Group

Prior to analysis, all study variables were screened for outliers and normality of distribution. Significant multivariate outliers were identified for two participants in the experimental group (standard residuals > 3.5) and replaced according to protocol set out by Tabachnick & Fidell, 2001).

Correlations among the study variables appear in Table 5.5.

Table 5.5
Correlation Matrix, Means, and Standard Deviations for Experimental Group (Study 2)

Variable	*M*	*SD*	1	2	3	4	5	6
1. Simulation Experience	.63	.48						
2. Pre-flight Competence	1.44	.14	.22					
3. State Anxiety	5.31	.98	.29*	.23				
4. DWMc Processing	.63	.48	-.01	-.26*	-.01			
5. DWMc Storage	.62	.15	-.32**	-.24	-.37**	.06		
6. Flight Error	2.29	.29	.25	.38**	.44**	-.14	-.46**	

Note. **p < .025*p < .05; DWMc = Dynamic Working Memory Capacity.

5.6.3.1 Test of Hypotheses on the Experimental Group (Threat of Shock)

5.6.3.1.1 Hypothesis 1a

The same analyses were rerun again, but for those in the experiment group. In Step 1, there was a significant effect of experience on flight error. Similarly, the addition of pre-flight competence in Step 2 and state anxiety in Step 3 were shown to yield significant effects on flight error. In Step 4, however, DWMc storage (B = -.29, t = -2.42, p = .019) but not DWMc processing (B = -.07, t = -0.63, p = .528) was found to affect flight error (Table 5.6).

Table 5.6
Hierarchical Results for DWMc on Flight Error Controlling for Incoming Ability Variables

Predictors	R^2	ΔR^2	*F*	B	T	Sig(p)
Step 1	.05*					
Simulation Experience				.25	1.99	.051
Step 2	.14*	.09	5.86			
Pre-flight Competence				.34	2.70	.008
Step 3	.25**	.09	7.78			
State Anxiety				.35	2.29	.005
Step 4	.30**	.4	6.24			
DWMc Processing				-.07	-.63	
DWMc Storage				-.29	-2.42	.019

Note. **p < .025*p < .05; DWMc = Dynamic Working Memory Capacity

5.6.3.1.2 Hypothesis 2a

A backward elimination procedure was computed on the study variables for the experimental group. As shown in Table 5.7, after taking into account state anxiety, and DWMc storage, no other variables reached significance in the reduced model.

Table 5.7
Summary Findings for Flight Error Regressed on Study Variables

	Univariate Model				Mulitvariate Model				Reduced Model			
Variable	B	SE	Β	Sig(p)	B	SE	β	Sig(p)	B	SE	Β	Sig(p)
Simulation Experience	.15	.07	.41	.051	.01	.07	.01	.952	-	-	-	-
Pre-flight Competence	.78	.24	.38	.003	.47	.24	.22	.061	-	-	-	-
State Anxiety	.13	.03	.44	< .001	.08	.03	.28	.024	-.08	.04	.27	.021
DWMc [i] Processing	-.08	.08	-.14	.282	-.04	.06	-.63	.528	-	-	-	-
DWMc Storage	-.89	.22	-.46	< .001	-.57	.23	-.29	.019	-.58	.22	-.30	.013

Note. [i] DWMc = Dynamic Working Memory capacity

A further regression was conducted to test for interaction effects between state anxiety, DWMc storage and flight error. All sources of variance, including state anxiety by DWMc storage term made significant contributions to the prediction of flight error, with the interaction term adding approximately 6% further explained variance to the model ($\Delta R^2 = 0.06$, see Table 5.8).

Table 5.8
Hierarchical Regression Results for State Anxiety with DWMc Storage on Flight Error

Predictors	R^2	ΔR^2	F	B	T	Sig(p)
Step 1	$.27^{**}$					
State Anxiety				.31	2.65	.010
DWMc Storage				-.34	-2.82	.006
Step 2	$.33^{**}$	.6	10.65^{**}			
State Anxiety				.28	2.42	.019
DWMc Storage				-.32	-2.82	.006
State Anxiety by DWMc Storage				-.26	-2.39	.020

Note. $^{**}p < .025$ $^{*}p < .05$; DWMc = Dynamic Working Memory Capacity. R^2, total explained variance; ΔR^2, change in explained variance by step; change in F-ratio by step; B, unstandardized regression coefficient; associated t-statistic.

Figure 5.6 shows the DWMc storage-error relationship at different levels of anxiety. As shown, the relationship between DWMc storage and flight error in both the low and high anxious groups emerged as negative, with the gradient for the high anxious group much steeper (approximately 16% steeper: low anxious group, B = -.32; and high anxious group; B = -.37).

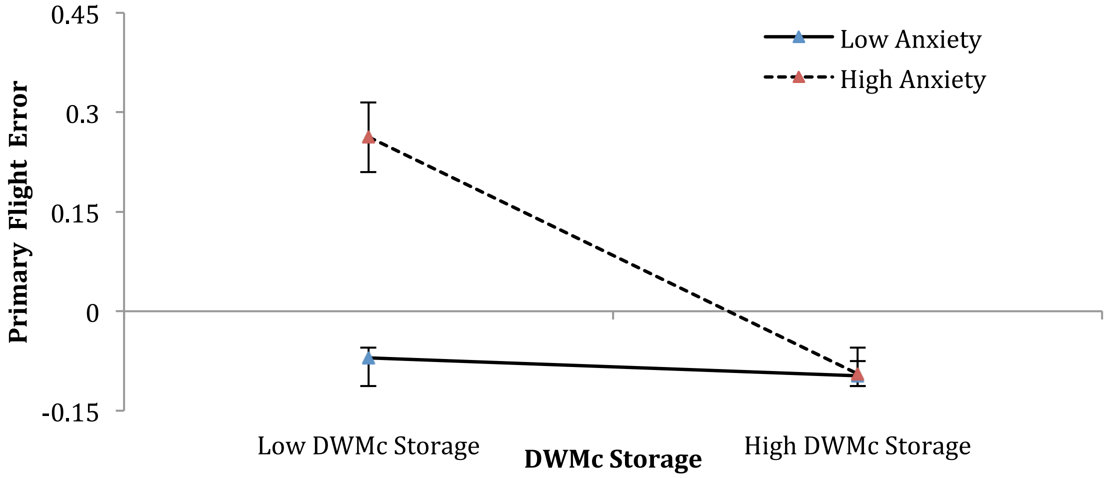

Figure 5.6 An Illustration of the anxiety by working memory capacity interaction effect on simulated flight

5.6.4 Qualitative Data on the Simulated Flight Task

Qualitative data was derived from post-experimental interviews conducted by the experimenter following the divided attention task for all participants. A thematic analysis was conducted by the experimenter and a colleague in "*which components or fragments of ideas or experiences, which often are meaningless when viewed alone*" (Leininger, 1985, p. 60) were classified into descriptive words. Qualitative data from participants revealed experiences ranging from very positive (e.g., fun and interesting) to neutral to somewhat negative (e.g., nerve-racking, stressful and unsettling). In response to the question regarding their experience relating to the divided attention task, 32% of participants in the control group and 28% in the experimental group stated it was stressful. Comparisons were therefore conducted for four groups (see below) for both the control and experimental conditions, respectively.

5.6.4.1 Control Group

(1) Low Anxiety/High WMc.

Scores on the STAI-S ranged from 2.0 to 5.4, with scores less than or equal to 3.2 being considered low in anxiety (see Conway et al., 2005). Of those participants, 17 had scores greater than .65 (or 65%) on the divided attention task. Review of Table 17.1 (see Appendix 11) revealed the words ‘cognitively challenging’ (n=8) and ‘interesting’ (n=8) as the most frequently cited words to describe the divided attention task.

(2) Low Anxiety/Low WMc.

Of the participants who scored less than 3.2 on the STAI-S, 14 had scores less than or equal to .65 (or 65%) on the divided attention task. These participants were therefore considered both low in anxiety and low in WMc. The most frequently cited words used to describe the divided attention task amongst this group were ‘absorbed’ (n =8), ‘cognitively demanding’ (n=6) and ‘effortful’ (n=5).

(3) High Anxiety/High WMc.

Scores greater than 3.2 on the STAI-S were considered high for the sample (see Conway et al., 2005). Of these participants, 18 scored greater than .65 (or 65%) on the divided attention task and, hence, these participants were considered both high in anxiety and high in WMc. Review of Table 17.3 (see Appendix 11) revealed that although one third of these participants described the task as ‘interesting’ (n = 6), more often than not, they described the task as ‘stressful’ (n=8) and ‘cognitively demanding’ (n=8), albeit by a frequency of 2 (equivalent to 10%).

(4) High Anxiety/Low WMc.

Of the participants who scored greater than 3.2 on the STAI-S, 14 had scores greater than .65 (or 65%) on the divided attention task. These participants were therefore considered both high in anxiety and low in WMc. Thus, these participants were thought to have a compounded difficulty given that they were not only highly anxious but, on account of their low WMc, did not have the necessary resources to offset (and therefore overcome) the negative effects of anxiety. Indeed, the most frequently cited words to describe the divided attention task were 'self-conscious' (n = 6), 'cognitively demanding' (n=6) and 'cognitively challenging' (n=5). Indeed, further inspection of Table 17.4 revealed that these participants also described the task as stressful (n = 4), tiring/exhausting (n = 4), with some even declaring the task as near impossible (n = 3).

5.6.4.2 Experimental Group

(1) Low Anxiety/High WMc.

STAI scores obtained by those in the experimental group were comparatively greater than those in the control group (M = 5.30 and M = 3.69, respectively) with scores ranging from 3.0 to 7.3. Accordingly participants who scored less than 5.0 were considered low in anxiety (see Conway et al., 2005). Of those participants, only 15 had scores greater than .65 on the divided attention task and were therefore considered both low in anxiety and high in WMc. In this context, participants described the divided attention task as 'exciting' (n=9), 'and nerve-racking (n=7).

(2) Low Anxiety/Low WMc.

Of the participants who scored less than 5.0 on the STAI-S, 15 had scores less than or equal to .65 (or 65%) on the divided attention task. These participants were therefore considered both low in anxiety and low in WMc. The most frequently cited words used to describe the divided attention task amongst this group were ‘cognitively demanding’(n=7) and ‘exhausting’ (n=6), which accord with theoretical models of cognition (i.e., PET and ACT).

(3) High Anxiety/High WMc.

Scores greater than or equal to 5.0 on the STAI-S were considered high for the experimental group. Of these participants, only 14 scored greater than .65 (or 65%) on the divided attention task and, hence, these participants were considered both high in anxiety and high in WMc. Review of Table 18.3 (see Appendix 12) revealed that one half of these participants described the task as ‘interesting’ (n=7), with 42% of the group also describing the task as both ‘nerve raking’ (n=6) and one where they were felt generally ‘strained’ (n= 6).

(4) High Anxiety/Low WMc.

Of the participants who scored greater than 5.0 on the STAI-S, 16 had scores greater than .65 (or 65%) on the divided attention task. Thus, these participants were grouped together as people having characteristics of both high anxiety and low WMc. In other words, these participants were thought to not have the necessary resources to offset (and therefore overcome) the negative effects of anxiety. In this context, the most frequently cited words to describe the divided attention task were ‘self-conscious’ (n=9), ‘burdensome’ (n=7) and ‘overwhelming’ (n=7). In general, these words reflect the greater level of stress that participants in the experimental group were under (see mean STAI-S scores from Tables 4.1 and 5.1) relative to the control group.

5.7 Discussion

Several changes were engineered to address the methodological issues that were revealed from the initial investigation (Study 1). First, an attempt was made to improve the measurement of threat-based cognitions by measuring physiological responses, such as GSR and HRV. Second, the design of Study 1 was extended to include a between-subject design with one group serving as the control (conditions matched to those of Study 1) and the other as the experiment (threat of shock). According to our main findings, both groups had comparable physiological arousal at baseline and pre-flight competence tests; however, where stress was manipulated (at the outset of the divided attention task), there was a general increase in GSR for those in the experimental group. More striking perhaps were the results on flight error (i.e., the dependent variable), which, for high-anxious individuals with high WMc, were notably reduced, and this moreover was despite their apparent heightened anxious state.

5.7.1 Investigating Goal 1: Physiological Differences Between the Control and Experimental Groups

With respect to mean GSR values, both groups showed comparable GSR across periods of rest (baseline characteristics) and tests of pre-flight competence. From a methodological standpoint, group differences during the course of investigation—especially prior to any manipulation—can suggest poor protocol. Indeed, only when exposed to an acute stressor (*threat of shock*) did group differences emerge, with those in the experimental group registering significantly increased skin conductance than those in the control group (see Figure 5.7).

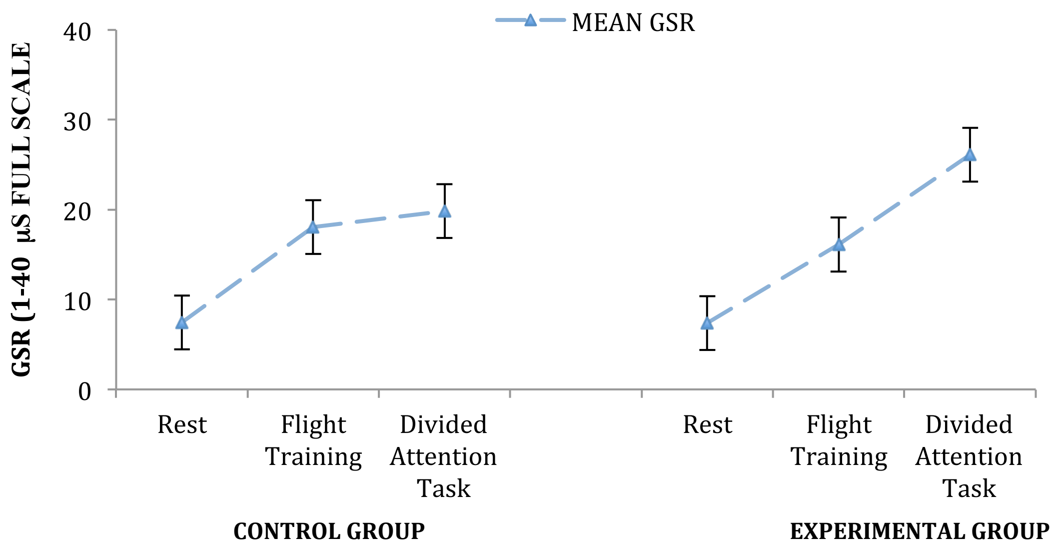

Figure 5.7 An Illustration of GSR Data for Study 2, Means and Standard Deviations Across Three Phases of the Laboratory Session

Here the negative relationship between threat-based cognitions and attentional processes are similar to findings reported elsewhere (Duncko, Johnson, Merikangas, & Grillon, 2009; Ishizuka, Hiller, & Beversdorf, 2007; Satchell, 1993; and Stokes & Kite, 1997). However, commenting on the mean GSR for a sample of participants may be rather meaningless, especially if consideration is not given to confounding factors such incoming health and/or fitness.

Following, then, the practice of Lee and Liu (2003), the incremental change in GSR (difference between work and rest rates, ΔGSR) was inspected (see figure 5.8). Importantly, when comparing the divided attention task to baseline characteristics at rest, ΔGSR was significantly higher in participants' in the experimental group—about 7.5 µS units higher on average (or about 19% on a scale ranging from 0 to a possible maximum of 40).

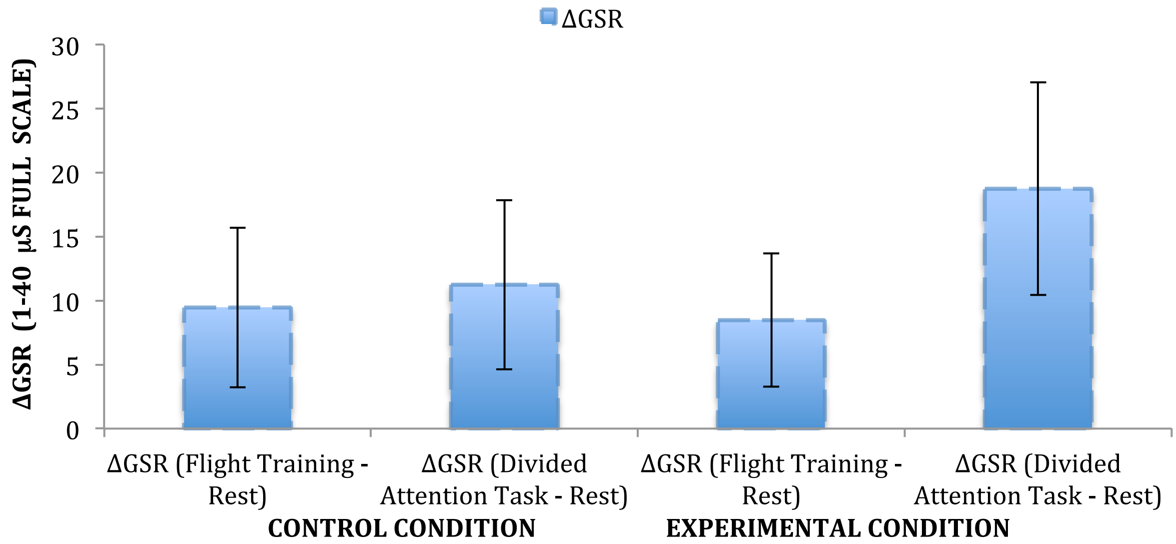

Figure.5.8 Average Mean ΔGSR in Control and Experimental groups. Bonferroni-Holm corrected independent samples t tests revealed that the experimental group (stressed participants) had significantly higher skin conductance compared to the control group at the Flight Training – Rest period; ** $p < .05$) and the Divided Attention Task –Rest period; ** $p < .05$). Data are presented as group mean ± standard deviation (raw data). GSR = Galvanic Skin Response.

Arguably, foremost among threat-based stressors is the psychological stress associated with *loss of control* (Bowers, 1968) and/or *predictability* (Geer, Davidson, & Gatchel, 1970; and Koolhaas et al., 2011). As a specific example applied to the human experience, Chapman and Hill (1989) and Chapman (1989) found that patients administered less opioid analgesics when able to self-medicate than if they were asked to wait on a nurse. Here the standard explanation for this is that in the latter case, the opioid analgesic is being requested both from the protracted discomfort and to quell the ambiguity or stressfulness of the lack of control and/or predictability. In the case of the present research, the threat of a random (and therefore unexpected) shock is likely to have evoked an appraisal process in which perceived demands exceeded available resources. However, a more parsimonious explanation might be that unexpected stressors tend to produce an attentional shift from external to internal processes (i.e., how they feel emotionally about the experience), leading to undesirable physiological outcomes (see Staal, 2004, but see also Koolhaas et al.).

In sum, the present findings support previous studies that report increases in skin conductivity with ascending mental workloads (e.g., Kaslsbeek & Ettema 1963; Opmeer, Krol, 1973; and Sekiguchi, Handa, Gotoh, 1978). The following section, therefore, explores the interplay between the study variables in a study context which was: (1) non-threatening, and thus non-metabolically demanding (i.e., the control group), and (2) threatening, and thus physiologically and metabolically demanding (i.e., the experimental group). We begin by investigating the control group.

5.7.2 Investigating Goal 2: Replication of Study 1 — Control Group

The results of the control group provide a close replication to the results of the first study. For instance, on possible scale ranging from 0 to a possible maximum of 1, the means for DWMc processing were consistent across study 1 (M = .58; SD = 49) and Study 2 (control group; M = .55; SD = 50). Notably, this was also true for the DWMc storage variable, with the means for study 1 (M = .65; SD = .15) and Study 2 (control group; M = .67; SD = .14) being similar in approximation.

Consistent with Study 1, the fixed capacity mechanism was shown to play a chief role in the prediction of flight error, and this was over and above measures of domain-specific skill (i.e., simulation experience and tests of pre-flight competence). Furthermore, it was found that this fixed capacity mechanism interacted with state anxiety to explain variance in flight error. Specifically, the obtained results demonstrated that high anxious individuals were shown to offset the negative effects of anxiety but only if they had necessary resources to do so. By comparison, when auxiliary resources were not available or simply did not exist, high anxious, but not low anxious, individuals were shown to have severely impaired performance.

Compelling as these findings are, the assumed ‘manifest’ stressfulness intrinsic to the study may limit its generalisability. Extrapolating from the previously analysed physiological data suggests that the physiological arousal engendered by the divided attention task was essentially the same as that for tests of pre-flight competence. In other words, compared with pre-flight competence the added burden of the WM task—in the divided attention task—was shown to only slightly increase skin conductance (sweat). Thus, the results obtained here may be interpreted as involving a moderate level of stress, or one that is perhaps comparable to learning a new task.

5.7.3 Investigating Goal 3: Extension of Study 1 — Experimental Group

In an effort to extend the external validity of the present research, the study tested the same hypotheses in a high-stress context.

5.7.3.1 To What Extent are Individual Differences in Complex Cognition ('Flight Error') Domain-General or Domain-Specific?

A preliminary analysis of correlations between both memory mechanisms and flight error revealed four significant or near-significant correlations: simulation experience with flight error (-.25, p = 0.51); pre-flight competence with flight error (-.38, p = 0.03); DWMc processing with flight error (-.14, p = 0.07) and DWMc storage with flight error (-.46, p < 0.001).

In the present research, both fixed capacity and domain-specific skill (i.e., pre-flight training) affected complex task performance, although the fixed capacity mechanism played a greater role (r = .38; and r = .46, respectively). Thus, the present findings are broadly consistent with Conway et al.'s (2005) view that WM "*predicts complex cognitive behaviour ... primarily because of the general, executive attention demands of the tasks, rather than the domain-specific demands of the task*" (p. 771). More specifically, the results provide some support for the prediction of skill acquisition theories and immediate-memory theories, which contend that fixed capacity (domain-general attention) plays a greater role in the initial stages of learning and skill acquisition than do domain-specific or acquired skill (e.g., personal preparation or pre-flight preparation).

Given, then, that WM (as fixed capacity) must in any case allow for more flexible cognitive processing (especially for those high in WMc), there remains still the question of how important this capacity is. For instance, given sufficient resources, the question might be asked, “To what extent are individual differences in WM (as a fixed capacity) useful for covering or limiting the stress response?” Or, more specifically, given the apparent negative mood sate (GSR being approximately 7.5 μS units higher on average than control), can anxious individuals (experimental group, Study 2) still overcome the stress response?

5.7.3.2 To What Extent are Individual Differences in WM (as a fixed capacity) Useful for Covering or Limiting the Stress Response?

Fragility of performance (called ‘*performance pressure’* by some researchers) is often associated with a strong desire to perform as well as possible. In the present study, participants’ motivation to do well and carry out the tasks seemed high, as participants were generally very committed and had clear goals. Paradoxically, despite the fact that elevated anxiety can pre-empt the limited resources of attention, pressure-packed, highly demanding situations are where high-anxious individuals may be most motivated (e.g., Deraskshan & Eysenck, 2011).

It was suggested above that, under the threat of shock, the WM task might have been so difficult as to pre-empt the processing and storage capacity of WM (especially the central executive). However, this in itself does not explain why (or how) high-and low-anxious individuals had comparable performance. Why is this the case? According to ACT (Eysenck et al., 2007), tasks that are demanding (and are therefore challenging) may work to motivate anxious individuals to use compensatory strategies (e.g., increased use of attentional control; see Eysenck et al., 2007). Indeed, qualitative data from the post-experimental interviews confirmed this (see section *5.6.4 Qualitative Data on the Simulate Flight Task*). Specifically, when asked to rate their level of motivation to complete the divided attention task, the mean rating, on a possible scale from 0 to a possible maximum of 5, was 4.7 (control group) and 4.6 (experimental group) – independent-samples t-test $t(121) = 1.38$, $p = .168$. Thus, it may be that when a task is demanding, overall task performance can be improved. Indeed, it may very well be the nature (and clarity) of the task that may begin to explain why (and when) anxious individuals first engage in the use of compensatory strategies.

Overall, the cognitive by threat-based cognitive interaction is consistent with theoretical frameworks that emphases both the role of motivation (e.g., Eysenck et al., 2007) and the use of compensatory strategies. Indeed, ACT provides a theoretical framework which may account for situations in which high-anxious individuals may perform relatively well, if not comparable, to their low-anxious counterparts. The results of the presented study, however, extend this proposition to suggest that this advantage is only possible if individuals first have the capacity (or cognitive resources) to offset the aversive anxious state (cf. Owens et al., 2012).

5.8 Limitations and Directions for Future Research

The study considers five important future directions for research. First, there is the issue of *cognitive workload* or *task engagement*. Studies 1 and 2 used what may be considered as typical flight phases of normal high cognitive load in civil aviation (Lee & Liu, 2003; but see also, Huttunen et al. 2010). Given that high spans—those with greater capacity—were able to overcome the anxious state, a useful amendment might be to manipulate task load by having participants' complete tasks of varying complexity. For example, in a related study, Radeborg, Briem and Hedman (1999) employed a single factor repeated measures design with three stages of complexity: (a) no driving; (b) easy driving; and (c) difficult driving. The authors found that being involved in the driving task (levels b and c) were associated with costs to both WM processing and storage (verbal span task) but whether the task was easy or difficult had no apparent effect on WM (Radeborg et al., 1999). It is worth noting, however, that the authors used two to four elements per item (in their span task), whereas the presented studies used up to five elements per item. Indeed, the item-size might be critised since, as Conway et al. (2005) notes, ranges from two to five elements per item are ideal for most student populations (cf. Conway et al., 2002). *Cognitive workload* or *task engagement*, therefore, presents as a useful variable to systematically manipulate.

Second, the recruitment of experts (civil or military) offers considerable potential for testing the predictions of ACT. Since the present research employed proxy measures of LT-WM (pre-existing ability), the findings are of general relevance to ACT. Indeed, previous investigations which have explored similar lines of enquiry have typically recruited experienced pilots or flight instructors (e.g., Sohn & Doane, 2004, total average flight time of 1116.8 hours; and Sohn & Doane, 2003, total average flight time of 907 hours) and compared their performance with novice or student pilots (e.g., Sohn & Doane, 2003, total average flight time of 60 hours). However, care should be taken when considering the present findings. Although military and commercial aviators (with fare paying passengers) represent a considerable proportion of the traffic volume and staff in aviation, the cognitive load imposed by human-machine interaction is notably different to the demands of civil and general aviation. This difference in some cases can relate to the various multi-task flight environments of different aircrafts, with large jet turbine aircraft requiring greater variability in workload compared to other more general aviation aircraft. Hence, the task of descending at 500 FPM in a new glass cockpit aircraft may present as a low workload due to automation, whereas in a light aircraft without the use of automation to assist (i.e., in a Cessna 172 single engine aircraft), may be a high workload. In any case, despite technological advances in human—machine interaction when too low or too high, cognitive load increases (and directly affects) the risk of flight accidents. Sustained operations like descending 500 FPM challenges the vigilance of the individual, and this is before taxing the capacity of the aviator with other tasks (e.g., processing secondary information).

Third, echoing the call by Eysenck et al. (2007), there is a need for research focusing on the strategies used by anxious individuals when processing becomes inefficient. Typically, anxious individuals increase expended effort or motivation to compensate for impaired processing; however, some strategies may be learned. For example, self-regulatory strategies such as reappraisal (and suppression) are helpful in lessening the influence of threat-based cognitions (Gross, 1999; Manstead & Fischer, 2000). Both regulatory strategies (reappraisal and suppression) have been widely studied across of number of domains, including experiential (Gross & John, 2003), physiological (Gross, 1998a) and cognitive domains (Johns, Inzlicht & Schmader, 2008; and Schmeichel, Volokhov & Demaree, 2008). As yet, there is insufficient knowledge of the affective consequences of emotion regulation, and how each of these may impact cognitive performance when processing becomes inefficient.

Fourth, according to the processing efficiency theory (and, the more recent, ACT), the most important distinction is between *effectiveness* (quality of performance) and *efficiency* (that is, the relationship between the effectiveness and the effort or resources spent in task performance). While the emphasis in the current research has been on *effectiveness* (generally, response accuracy), it is recommend that future research investigate measures of efficiency, such as the length of time taken to achieve a given level of performance. For example, *time versus accuracy* studies have shown that efficiency typically decreases as more resources are invested to attain a given level of performance. It follows, then, that when low and high anxious groups have comparable response accuracy (i.e., performance effectiveness), group differences in efficiency may be inferred from lengthened response times (e.g., Richards, French, Keogh, & Carter, 2000).

Fifth, most investigations of WM and flight performance have been based on a theoretical framework in which the central executive was regarded as unitary (for a review, see Eysenck et al., 2007). The present study, however, went some way to testing the updating function of central executive. Future research may consider testing the other functions of the central executive, such as the inhibition function—that is, one's ability to deliberately suppress (via attentional control) task-irrelevant stimuli.

In conclusion, the data provide a clear suggestion of a role WMc has in successful flight performance. In addition, the present findings extend previous research to highlight WMc as fixed capacity ('domain-general') mechanism in which to explain the effect of threat-based cognitions (i.e., anxiety) on complex cognition. It was argued that low WMc acts much like a 'secondary task' in dual task paradigms by preempting the limited attentional resources of WM. That is, when task demands increase to become excessive, those individuals with lesser capacity (or those with less 'cognitive workspace') are predicted to have already exhausted their resource pool, and this is before threat-based cognitions are factored in. However, where auxiliary processing resources are available, potential performance improvement in high WMc individuals with anxiety is likely explained by an increased motivation to minimise the aversive state. To address this proposition more clearly, measures of efficiency (*time versus accurac*y studies) should be employed in future research (for reviews, see Deraskshan & Eysenck, 2011; and Eysenck et al., 2007).

Six: General Discussion

6.1 Introduction

Two studies were designed to explore the effects of threat-based cognitions in a task with an updating structure that might make performance susceptible to failure via the threat of shock, at least at low levels of shock, with a probable move of mechanisms to executive functions via top-down attentional control. Cognitive interference theories suggest that anxious individuals habitually orientate to (or more often have hindered disengagement from) threat-based stimuli. Attention to threat-based stimuli at this component level is thought to impair the efficient functioning of the goal-directed system (Posner & Petersen, 1990) and it has been conjectured that behavioural regulation at this level might also disrupt the stimulus driven system (Corbetta & Shulman, 2002). However, theories of attention, such as attentional control theory (Eysenck et al., 2007), propose that threat-based cognitions might serve to motivate individuals to minimise the anxious state. If auxiliary processing resources are available, impaired performance is less likely to occur but only if it leads to the use of compensatory strategies (e.g., increased use of attentional control).

Study 1 was aimed at investigating subjects' ability to maintain a rate of decent, while doing some secondary task—a task whose performance should correspond most closely to what Shallice and Burgess (1993) saw as typical conditions requiring an active supervisory attentional system (counterpart to the central executive proposed by Baddeley 1986; 2001). The results indicated that, when simultaneously engaged in a primarily cognitive secondary task, subjects' ability to maintain a rate of descent was impaired by about 142 feet per minute.

As to the mood state of the individual, the mean state anxiety score for the sample was 35.60 (range 20-57; SD=8.08). Not surprisingly, individuals in this stress context performed at a significantly lower accuracy level on the secondary task (M=.65, SD=.15) than they did on a comparable experimenter-paced version of WM (M=.75, SD=.13). However, this lower accuracy was limited to components of WM only with the heaviest demands (specifically, the storage component). Furthermore, analyses also showed that such measures (1) *added* to the prediction of flight error, and this was over and above pre-existing abilities (simulation experience and pre-flight competence); and (2) *interacted* with threat-based cognitions such that high-anxious individuals were able to overcome the anxious state.

Study 2 extended the examination of attentional control under stress to include a condition in which subjects were under the threat of shock (experimental group). Here individuals in the experimental group had significantly increased levels of state anxiety and physiological arousal compared with the control group of participants (counterpart to those in Study 1). Again, individuals showed performance decrements on only the most capacity-demanding components of WM. Again, performance on these measures––the storage component—was found to interact with state-anxiety.

These findings are broadly consistent with attentional control theory (Eysenck et al., 2007) and demonstrate that high-anxious individuals may, given sufficient resources, overcome the aversive state. In particular, threat-based cognitions via threat of shock may occur in tasks that require *active processing* of material with concurrent demands on processing and storage rather than retrieval of *immediate* information from STM (Calvo & Eysenck, 1996; Calvo et al., 1994; and Calvo, Ramos, & Estevez, 1992) or LTM (Conway, Kane, & Engle, 2003).

It should be noted that in both of the two studies, the test of state-anxiety was always completed subsequent to the divided attention task. This sequence was designed to make the reference point the divided attention task and *not* the experience during the affect induction period or earlier (as in, e.g., Moore & Oaksford, 2002; and Wetherell, Reynolds, Gatz, & Pedersen, 2002). In fact, for both studies, the questions pertaining to threat-based cognitions were always in reference to the experience of the divided attention task. This retrospective assessment does allow for the possibility that the effects reported above are due to certain biases rather than threat-based cognitions per se (e.g., memory lapses). However, having the test of state anxiety always follow (immediately) the divided attention task should only allow for states of anxiety to be more salient. It could be further argued that the self-report measures in Studies 1 and 2 were insensitive to the *magnitude* of threat-based cognitions (i.e., anxiety) experienced during the divided attention task. However, the fact that HRV and GSR data was found to validate the self-report data in Study 2 (and Study 1), suggests that the biases often associated with self-report data were not responsible for the observed results.

Additionally, one might question the soundness of the above results based on the potential 'tradeoff' within the divided attention task (i.e., between the primary flight task and secondary WM task). For dual-task situations, one must create a 'dual-task environment' in which attentional control is divided between both the primary and secondary tasks. In terms of the covariation between the two tasks, examination of product moment correlations should show whether one task is favoured 'in lieu' of another. That is, if one task were neglected (or preferentially favoured) 'in lieu' of another, then a positive correlation should emerge. Importantly, the correlations that did emerge were negative: decreases in flight error (better flight performance) were associated with concomitant increases in WM.

Although finding support general immediate-memory theories in complex cognition and casts considerable light on the lower level function of updating, it also begs further questioning. Namely, given the disharmonious support for stress and the updating function outlined in the introduction, how can attention and updating be a viable explanation for higher-order cognition?

6.2 Impact of Stress on the Updating Function of the Central Executive

It may be that a robust framework based on top-down (goal-directed) versus bottom-up (stimulus-driven) attention is sufficient to solve this dilemma: threat-based cognitions create performance decrements under stress in tasks that engage attention and reduce the efficient functioning of the central executive, whereas non-stress conditions create limits on STM storage (Friedman & Miyake, 2004). However, although this hypothesis is somewhat appealing, it is thus nevertheless too simple or, as Eysenck and Derakshan, (2009) notes, "*not …very explicit*" (p. 959). Two kinds of research may, for example, work against it.

The first body research is that the adverse effects of increased influence of the stimulus-driven system can be reduced or eliminated when it leads to the use of compensatory strategies (Eysenck et al., 2007). This applies to demanding tasks (Eysenck & Derakshan, 2009) as well as to the experiments on more complex primarily cognitive tasks in the present work. Tasks such as these are thought to instigate a control system that can allocate extra processing resources, if needed, to a given task (Eysenck & Calvo, 1992). Thus, the particular system (Corbetta & Shulman, 2002; Posner & Petersen, 1990) that underlies attentional control is not the same for all updating tasks. Moreover, this difference in how threat-based cognitions affect the updating function appears to matter in terms of whether an individual is first motivated to reduce the anxious state.

The second body of research is related to the first. Not all *domain-general* tasks demonstrate performance decrements under stress: sensorimotor skills do not, and this is puzzling. WM intensive sensorimotor tasks are based on declaratively accessible 'performance rules' (Salvucci, 2001, 2002, 2007), which, while unpracticed, can be called upon during dual-task manipulations (e.g., Radeborg et al., 1999, and Gray, 2004). Hence, participants performing these tasks should show signs of increased motivation due the demanding nature of the task, just as participants in the present work showed for maintaining their rate of decent. To test this idea, albeit indirectly, Hayes, MacLeod, and Hammond (2009) had participants perform a category learning task under low or high motivational conditions. In the former condition, high-anxiety had a negative effect on performance, but this was essentially eliminated in the high-motivation condition.

6.3 The Potential Role of Motivation and the Updating Function

Thus, a goal-directed versus stimulus-directed distinction does not appear to fully explain the updating-stress results to date. It may be that the imposition of threat-based cognitions create two effects that alter how cognitive processes are allocated: (a) anxiety involves *cognitive interference* by preempting the limited attentional resources of WM; and (b) at the same time, threat-based cognitions prompt (via motivation) high-anxious individuals to over-ride the influence of the stimulus-driven system. However, it may be that effects (a) and (b) are differentially relevant to performance depending on the nature of the task (whether it is demanding or undemanding or whether it is practiced or unpracticed; Eysenck & Derakshan, 2009) – a sort of two-stage process (Eysenck et al. 2011).

Threat-based cognitions may be associated with an *underactivation* of cognitive control or it may be associated with a meaningful (but inefficient) recruitment of attentional control. In the former case, the underactivation of cognitive control is likely to occur when a task is undemanding, such as in case of everyday cognitive failures. For the high-anxious individual, this is often accompanied with a low motivation to complete the task. Under more onerous conditions, however, task goals are likely to be clear, and so such contexts set the occasion for an increased drive or *motivation* to reduce the influence of the stimulus-driven system. Here cognitive task performance should improve as a consequence of additional motivation to perform well. Indeed, on a possible scale from 0 to a possible maximum of 5, the mean rating for the clarity of task goals on the flight task was the maximum of 5, and this was across both studies and for every participant. Moreover, post-experimental data also showed that high-anxious individuals were not only clear on the task requirements but also very motivated to do the task well: Although they often described the flight task as “stressful”, they also described it as both “challenging and demanding”, where on a possible scale from 0 to a possible maximum of 5, the mean motivation rating was 4.3 (for Study 1) and 4.5 (for Study 2).

Indirect support for threat-based (‘anxiety’)-linked task performance was reported by Hayes, MacLeod, & Hammond (2009). They used a category-learning task to examine the extent that a task increases the likelihood of effort (cf. Eysenck et al. 2011) under low and high motivational conditions. Support was found for the attentional control model (Eysenck et al. 2007), where high anxious individuals performed poorly in the low motivation condition, but this ‘threat-based (‘anxiety’)-linked task performance’ was eliminated in the high-motivation condition. These findings suggest that increase in effort (i.e., use of processing uses) between the low-and-high motivation conditions was greater for the high-anxious participant. In sum, it appears there are two possible effects of negative mood states (i.e., anxiety) on attention control – first, anxiety can be associated with deficient recruitment of processing resources or, alternatively, it can be associated with meaningful (but inefficient) recruitment of such resources (see Eysenck et al. 2011, for a review of the two-stage process).

6.3.1 To What Extent are Individual Differences in Cognitive Task Performance Domain-General or Domain-Specific?

The present research represents a quantification of the respective roles of domain-general and domain specific skill in a complex aviation task environment. The chief reason for this quantification was essentially to shed light on the possible causes of the association often found between updating tasks (i.e., so called WM or span tasks) and cognitive abilities. Although previous investigations in the immediate-memory area have explored the two contrasting loci (e.g., Sohn & Doane, 2003; 2004), the present research took this investigation a step further. Specifically, it entailed thorough analyses of various tests of WMc in an effort to understand why domain-specific skills may be less predictive of cognitive task performance than domain-general attention.

It is a truism that domain-general attention is a devoted 'online' system dedicated to maintaining immediate-information in an easily accessible state. Thus, the theoretical backbone of this thesis was that WM tasks predict cognitive tasks primarily because of the "*executive attention demands of the task, rather than the domain-specific demands of the task*" (Conway et al., 2005, p. 771). Consistent with this view, results showed that domain-general attention (i.e., WMc) explained about twice as much variance in flight error as compared with measures of domain-specific skill, namely pre-existing simulation experience and pre-flight competence.

The sharp difference between these contrasting loci may be the difference between the presumed control processes dedicated to keeping immediate-information in an active (albeit transient) state. Critical to the view of this thesis then is that, while the ability to control attention can be useful in many critical task situations, it is most necessary under concurrent task management—this is because without threat-based cognitions, *task-relevant* information (e.g., acquired or pre-existing declarative knowledge) "*may be easily retrieved from LTWM as needed*" (p. 638, Kane & Engle, 2002). Thus, under concurrent task management conditions, *task-irrelevant* information and response tendencies are easily accessible, and so such instances beget a reliance on domain-general attention (e.g., Kane et al., 2004, and Colom & Shih, 2004). In other words, even if domain-specific skills were available, it is likely that to properly access them (or even call upon them) would require first the use of an attention capability. Thus, given the significance of the domain-general attention mechanism, it seems somewhat essential to document and describe the beneficial effect that influences the possession of this critical—albeit limited—personal resource.

6.3.2 To What Extent are Individual Differences in WM (as a fixed capacity) Useful for Covering or Limiting the Stress Response?

If the domain-general mechanism and state anxiety interact, how do the two constructs work together? The presented studies provide an interesting insight into their interplay. Consistent with the theoretical views of attentional control theory, the present findings suggest that such constructs interact in such a way that performers with higher levels of anxiety rely more on domain-general attention during the performance of complex cognitive tasks (cf. Owens et al., 2012). Stated differently, processing *inefficiencies* engendered by threat-based cognitions may be indexed by a smaller ratio of task quality to the use of processing resources for high-anxious individuals than for low-anxious individuals. This suggests that, given sufficient resources, high anxious-individuals may overcome the adverse effects of anxiety.

To elaborate, while it is often assumed that threat-based cognitions disrupt WM processes leading to internal ruminations to dispel negative moods states (Borkovec & Roemer, 1995), the experience of anxiety may also have some facilitating effects, including increasing the adoption of achievement goals (e.g., Owens et al., 2012). This argument is consistent then with findings where high anxious individuals are shown to perform on par with low anxious individuals, but in terms of performance effectiveness (or task quality per se) they are less efficient (e.g., Hadwin, Brogan, & Stevenson, 2005). In this way, the effects of anxiety appear to be constrained by the availability or efficiency of the motivating factors that can be accessed through the WMc mechanism.

In short, one of the most glaring limitations of most, if not all, immediate-memory theories is that they often fail to fully account for situations in which anxious individuals may perform relatively well on cognitive tasks. Attentional control theory, does, however, account for the increased motivation of high-anxious individuals, especially when it leads to the use of compensatory strategies (e.g., increased use of attentional control). The presented studies, nevertheless, extend this proposition to suggest that this advantage is only realistic if persons first have sufficient resources to offset (or cope) with the negative effects of anxiety (cf. Owens et al., 2012; but see also Eysenck & Derakshan, 2011). Thus, the presented studies suggest a possible expansion of theory to encompass situations in which threat-based cognitions may actually, given sufficient resources, facilitate performance. Moreover, discourse on the effect of threat-based cognitions on performance, such as Eysenck et al.'s attentional control theory, may be incomplete if it does not consider the role of motivation, since it cannot fully reflect for the differential impact that negative mood states had on cognitive task performance as observed in the presented studies (Mattarella-Micke et al., 2011).

In conclusion, the presented studies suggest that a low level of WMc (i.e., domain-general attention) acts much like the processing component (or 'secondary task') does in WM tasks limiting the cognitive workspace available. In the case of individuals with low WMc, the resource pool is already exhausted before factoring in the deleterious or negative effects of threat-based cognition (i.e., anxiety). Thus, performance improvements in high WMc persons with high anxiety is likely explained by an increased drive to do well on the task which is driven by (a) negative mood states and (b) the nature of the task at hand (demanding task; clear task goals). Whereas for those with low domain-general attention (i.e., low WMc) threat-based cognitions become deleterious, in those with high domain-general attention (i.e., high WMc), the additional cognitive workspace means that such people have the personal resources to act successfully act on their motivates. To address this proposition more clearly, aspects of motivation and processes of effortful control should be explicitly measured in future research (e.g., Valiente, Lemery-Chalfant, & Swanson, 2010). Nevertheless, continuing in the same vein as Eysenck and Derakshan's (2011) work, this thesis has thus identified domain-general attention (i.e., WMc) as a determinant factor via which improved performance may be achieved.

6.5 Limitations and Future Directions

Although the study serves well to illustrate that anxious individuals may, given sufficient resources, overcome the stress response, it is useful to note several limitations of this study with respect to the tasks employed. First, the flying task, where subjects maintained a constant rate of decent without the option to suspend or defer tasks, provided a well-controlled (naturalistic) environment in which we could investigate the effects of "cognitive distraction" on human cognition. However, it is clearly important to extend the present work to consider more challenging flight phases that would better represent real-world flight situations. Indeed, the two-presented studies are well suited for this extension due to the fact that, across both studies, the primary flight tasks were essentially of normal to moderate cognitive load (Huttenen et al., 2010).

Second, the secondary verbal WM task used set sizes of predictable sequence of list length (5 items in 8 blocks). The verbal task could be improved by varying the set size length (2 to 5 items), thus, as for the flight task, increasing the realism and validity of the analysis. Randomising the presentation order (and set size) might therefore mitigate the potential for developing any idiosyncratic strategies from knowing the size of the memory set (Conway et al., 2005). However, although this may deconfound item size, the early presence of difficult items (e.g., 5 items) may concomitantly discourage certain participants, particularly those less able (i.e., low WMc individuals or clinically anxious people). It is recommended therefore that fellow researchers make very clear that perfect recall is not expected of the participant. In addition, it could be argued that limitations apply in relation to the tested model, particularly its ability to account for two important aspects of behaviour: efficiency and effectiveness. The most glaring example of individual differences in efficiency and effectiveness in the simulated flight task arose in participants' attempts to manage the demands of the secondary WM task. The participants all generally started out attending to the WM task, for instance, using the maximum allotted time (20-seconds) to recall the to-be-remembered items (5 in all). However, some participants began to adapt as they became more familiar with the task demands. In particular, a few participants were able to report the to-be-remembered items quicker and more efficiently (<10-seconds). The model presented here did not account for individual differences in processing efficiency between the participant and their effectiveness in doing the WM task (i.e., task quality).

6.6 Strengths and Practical Applications of the Presented Studies

Clearly, the presented studies have numerous practical applications for individuals' in complex cognitive task environments. For instance, considering the specific application to simulated flight, this research helps in illuminating an interesting issue for comparing individual differences in a complex aviation task environment: the interplay between state anxiety, the ability to control attention and the potential effects on aviator performance. It is conceivable to assume that, generally speaking, threat-based cognitions will often result in deficient recruitment (or use) of attentional control mechanisms. However, in the present study, anxious individuals were able to perform on par with their low-anxious counterparts, but, in terms of cost, had to expend greater effort. Thus, while the currently experienced level of anxiety may certainly affect flight performance, it is clearly not the only factor, and the attentional control theory may go some way to "*explicate the relationship between anxiety and other contributing factors*" (Derkakshan & Eysenck, 2011, p. 995). Such comparisons can in turn facilitate the incorporation of other potential factors (e.g., demanding task conditions; clear task goals) in the comparison of individual differences in cognitive task performance, particularly in the early stages of the learning of a novel task.

An extensive practical application of the approach to complex aviation task environments will require more practical strategies (e.g., emotion regulation strategies) for designers and practitioners in order to evaluate if the stress response can truly be overcome. It would be interesting to explore whether emotional regulation strategies could further benefit those high-anxious individuals with presumably greater WMc (i.e., attentional control). For example, cognitive reappraisal is a particular 'antecedent-focused' strategy in which individuals may re-evaluate a situation in a more neutral manner. Admittedly, while the application of these strategies will allow for more rigorous and robust data, it may also complicate the modeling effort. For instance, although antecedent-focused strategies predict changes in affective processes (e.g., Gross & John, 2003; Schmeichel et al., 2008) their use in turn also creates a further load or limits on the overall WM system.

In addition, the presented studies have implications for clinically anxious groups where emotional dysregulation is especially common (e.g., Schweizer & Dalgleish, 2011). As is well known, these groups typically demonstrate a vulnerability to the suppression of threat-based cognitions, whether that information is internal (e.g., negative self-preoccupation) or external (e.g., threatening task-irrelevant distractors).

What is not clear is whether these groups would benefit, as did the participants in the present study, from the use of compensatory strategies (e.g., increased use of attentional control mechanisms). In addition, the implications, particularly for the clinically anxious, could then extend to everyday cognitive activities. Poorer recruitment of processing resources can leave individuals highly defeated and thus incapable of completing an otherwise routine task. In the present study, training and familiarity with a particular task (pre-flight competence; clear task goals) were found to help participants overcome some of the threat-based cognitions and enhance positive outcomes. Given, then, the relationship between state anxiety and cognitive task performance was negative in the low WMc group (studies 1 and 2), young adults with poor WMc (i.e., low domain-general attention) are likely to benefit the most from any intervention that aims to improve WMc (e.g., demanding situation; clear goals) or reduce the symptoms of threat-based cognition (i.e., anxiety).

Finally, there are a host of implications (including procedural recommendations) for the administration of WM tasks. According to ACT, WM tasks provide a relatively pure measure of WM capacity or transient storage. However, if administered under more onerous conditions, such as under the threat of shock, then the task itself may become more a measure of attentional control than of transient storage (Eysenck et al., 2007). This thesis exhibits this idea primarily in the comparison of the effects of two administration methods on WM task scores and their predictive power (r = -.43 vs. -.55, respectively; study 1). Here the results form a coherent picture of what happens when an updating task is performed (and administered) under differing stress conditions. Although both WM tasks share essentially the same underlying structure, the additional stress load when the WM task was administered as a secondary task—and not a standalone primary task—*does* result in more constrained (or lower) span scores. More important, the extra load (presumably on the updating function) *does not* simply move the resulting span scores down the distribution; rather, it changes, at least for negative-mood state people, the nature of what the WM task actually measures (i.e., WMc vs. attentional control).

Updating tasks may therefore have an application in other domains investigating multi-tasking abilities, such as in driver distraction (Salvucci & Macuga, 2001), particularly in the study of "cognitive distraction" (Salvucci, 2001, 2002, 2006, 2007). Indeed, while driver performance is often associated with negative effects on perceptual-motor-processes (e.g., dialing a mobile telephone), researchers have now found that cognitive distraction can also arise from purely cognitive secondary tasks such as the carrying on of difficult conversation (e.g., Alm & Nilsson, 1995; cf. Salvucci, 2002). These studies, however, are not fully consistent across the immediate-memory literature and seem to depend highly on the type of secondary task (i.e., perceptual-motor vs. cognitive task) as well as on the particular task being performed (easy vs. difficult; Radeborg et al., 1999). Thus, it remains for future research to clarify this issue.

6.7 Concluding Remarks and Conclusion

Two studies were carried out aimed at addressing several issues related to WM tasks and their presumed relationship with cognitive task performance and the updating function of the central executive. While it is conceivable that many of the findings may extend to other types of WM span tasks (Conway et al., 2005), the generalisability of the present findings to immediate-memory theories, among all the available measures of WMc, certainly needs to be tested. Moreover, because the study recruited a sample of university students and focused on flight error as a criterion construct of interest, it also remains to be seen whether these findings generalise to other samples (i.e., experienced aviators; the clinically anxious, etc.) and to other criterion measures (e.g., situation awareness; navigational knowledge, etc.). Overall, however, it is hoped that the presented studies provide a useful basis from which to investigate self-help, human error and complex cognitive task performance.

In this thesis, significant effort was made to delineate between both the administrative and theoretical aspects of the study, but in actuality the two notions are closely related. As the results for the two administration conditions (i.e., primary vs. secondary administration) have clearly illustrated, the methodology with which a researcher administers (or chooses to administer) an updating task can have significant bearing on what the task actually measures. Thus, the thesis concludes on a constructive note by presenting several concrete recommendations for using WM and hence updating tasks, with specific reference to threat-based cognitions and the updating function.

(1) Do not allow substantial delays between stimulus presentation

A critical feature of the processing component of WM and hence updating tasks is that it interferes with rehearsal. In the case of the operation span, substantial delays between each new operation-word string may permit rehearsal of to-be-remembered items, leading to a task that is more representative of immediate-storage than of executive functioning. Yet even with more closely monitored 'experimenter-paced' versions (as in Study 1), most participants will at some point attempt to implement some form of idiosyncratic strategy. In fact, many will often pause at the onset of a new operation-word string, just as participants in the present work did, despite strong instructions not to do so. Thus, if administered individually, the researcher should pay special attention as to how the participant is processing the operation-word string and intervene immediately when (and if) they pause. Of course, if processing is done silently (as in the divided attention task; Studies 1 and 2), there is no way to monitor if the participant is stalling. In such cases, it is essential that the researcher impose a fairly strict deadline (e.g., 4 seconds) to ensure the participant is not allowed anytime beyond that needed to process the stimuli. It is worth stressing, that if a deadline is used, there must be a requirement that each stimulus subsequent to the first stimulus be presented immediately (Saito & Miyake, 2004) or else additional time may permit rehearsal (see Friedman & Miyake, 2004).

(2) Include an accuracy criterion on the processing component of the WM task

As discussed earlier (see point 1), it may be difficult to ascertain whether a participant has attempted to engage in a tradeoff between processing and storage demands of the WM task. As in the present thesis, it is recommended that researchers impose a certain level of accuracy (typically, 85%; e.g., Conway et al., 2005) on the processing component of the WM task. That is, data should only be taken into account if participants produce a near perfect score on the verification component of the task (i.e., identifying the veracity of a sentence or equation).

(3) Include task Ensure there is sufficient item-size

Although WM (and hence updating) tasks share an underlying structure and are implemented in much the way, there is still considerable debate over how many items to include in a set (e.g., 2 – 5). Whereas some researchers have used smaller items sizes (from two to four; e.g., Jones, Beath & Kindred, 2012, unpublished data), those with larger set sizes are ideal because they mitigate the potential for ceiling effects, especially among those participants in the upper end of the performance distribution. Consistent with Conway et al., (2005), it is recommended that set sizes range from two to five elements per item (Conway et al., 2002; and Kane et al., 2004). Such criteria and consideration may be valuable when trying to interpret null or unexpected results.

(4) When possible, include a stressor that creates a lasting affect

The advantages of stress conditions over non-stress conditions can be identified by reconsidering the nature of the updating function described earlier. According to attentional control theory, there are no effects of anxiety on the updating function assessed by either WM or updating tasks when conditions are non-stressful (e.g. Calvo & Eysenck, 1996; Calvo et al., 1994, 1992). In contrast, when conditions are stressful, the overall demands on the updating function appear to systematically increase, although these findings are “inconsistent and difficult to interpret” (p348, Eysenck et al., 2007). Discrepancies in the stress and WM area may, however, be explained by assuming that physiological stressors (e.g., threat of shock) impose greater demands on the updating function than psychosocial or psychological stressors, which are both notoriously fleeting and easily suppressed by task engagement (e.g. close observation by the experimenter; Shackman et al., 2006). Thus, in studies interested in studying the effects of anxiety on WM performance, it is recommended that researchers employ stressors that stronger employ physiological stress inducing components. Although it is often difficult to tell which studies have used less than optimal stressors, consideration of differing stress inducing protocols may reconcile the conflicting results in the literature, particularly those concerning the relations between anxiety and the updating function (Eysenck et al., 2007).

(5) When possible, include standard measure (or multiple measures) of WMc in the design

Finally, it may be virtually impossible to determine the utility of an administrative method if it there is no standard by which to compare it. However, the two administrative methods (i.e., primary vs. secondary administration) in this thesis differed markedly in the extent that they correlated with the criterion construct of interest, namely simulated flight (or ‘flight error’). Hence, including a standard measure of WMc may be useful. In many cases, researchers often focus on the extent to which performance on a WM correlates with performance on some practically and theoretically important criterion construct of interest. In these designs, it is helpful to consider whether the particular ‘version’ of a WM task is measuring the same underlying ‘thing’ or construct as other widely accepted and more standard versions of the same task. Thus, if the WM task correlates well with a standard WM task, then the researcher can be confident in whatever findings result, null or not. This is especially important when a researcher is experimentally manipulating the WM task so that they can verify whether altered versions—different administration methods—still tap the same underlying construct as the original, standard version.

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7 Appendix 1

INFORMATION SHEET AND CONSENT FORM (Study 1)

Title: *INDIVIDUAL DIFFERENCES IN WORKING MEMORY*

You are invited to participate in a study of working memory. The purpose of the study is to examine how individual differences impact working memory in a simulated flight. The study is being conducted by Mr. David Loe, a student of the Doctor of Organisational Psychology programme at Macquarie University, Sydney. The academic supervisor of the research is Associate Professor Colin Wastell of the Department of Psychology, Faculty of Human Sciences. Their contact details are as follows:

Mr. David Loe 0404 943 181

Associate Professor Colin Wastell 02-9850-8600

Upon arrival you will be asked to provide a *unique 6-letter/number code.* If you decide to participate, you will first complete a 20-minute automated working memory task. Upon completion, you will then undertake a simulated flight task in a RedBird FMX Flight Simulator. The simulated flight and working memory task will take about 20 minutes, and includes training in the RedBird FMX Flight Simulator and in the use of a hands free communication device. Immediately following the flight task, you will complete a questionnaire. This will take approximately 4 minutes and will ask you to respond to a number of statements, which people have used to describe themselves and how they generally feel. Shortly after, the experimenter will then conduct a short post-experimental interview with you. While it is not expected that the questionnaire or simulated flight will be distressing, any prolonged discomfort should be reported to the researcher as soon as possible.

Any information or personal details gathered in the course of the study are confidential. No individual will be identified in any publication of the results. The data will be accessed by the persons listed above, but limited access, where you will not be identified with a particular survey or experimental data, may be provided to persons assisting in the analysis. If you decide to participate, you are still free to withdraw from further participation in the research at any time without having to give reason and without consequence. Whether you chose to proceed with completing either task or chose not to do so feedback relating to the study will be made available to you. To receive this feedback you may provide the researcher with an email address to which a summary will be forwarded on completion. If you do not wish to provide these details at this point you may choose to contact the researcher on the above numbers should you wish to receive feedback at a later date. Alternatively, a summary of the results will be made available on the Macquarie University organisational psychology page (http://www.psy.mq.edu.au/orgpsych@mq). If you have any further questions about the research, please feel free to contact Mr. David Loe at david.loe@students.mq.edu.au.

I, ________________________________ have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to participate in this research, knowing that I can withdraw from further participation in the research at any time without consequences. I have been given a copy of this form to keep.

Participant's Name:

Participant's Signature: ________________________________Date:

Investigator's Name: DAVID LOE

Investigator's Signature: ________________________________Date:

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

8 Appendix 2

EXPERIMENTER-PACED - *O*Span TASK

In this experiment you will try to memorise words you see on the screen. However, to make it more difficult, you will have to do a second task between the presentation of each word. Specifically, you will have to solve simple math problems.

Here is an answer sheet that you will use to write down the words you remember.

You will see an equation and a word appear on the screen. Your job is to read the equation OUT LOUD, then verify if the answer provided is correct or not by saying "yes" or "no," and then immediately read the word that follows the equation OUT LOUD.

Let's take a look at an example, to make your task clearer. If I pressed the space bar and you saw the following:

IS 2 + 1 = 3 ? DOG

You would read the equation out loud, "Is 2 plus 1 equal to 3?" then you would say "yes," because 2 plus 1 DOES equal 3, and then you would immediately say "dog." When you say "dog" you should try to remember it for a later test.

After you say the word aloud, such as "dog," ***I will hit the space bar again****, and you will see a new equation and word appear on the screen, for example:*

IS 3 + 4 = 5 ? SNOW

Here, you would say, out loud: "Is 3 plus 4 equal to 5?... no.. snow." Here you would say "no" because 3 + 4 = 7, not 5. Don't forget to always read the word that follows the equation out loud.

After some number of these equations and words, you will see three question marks appear in the center of the screen like this:

???

This is your cue to write down all the words that you saw in that set, in the same order you saw them in.

So, for this example, you would write "dog" in the first blank on your answer sheet, and "snow" in the second blank, going from left to right.

Your job in this task is to memorise the words you see on the screen while you also solve the math problems. Here is a more accurate example of what the math problems are really going to look like:

IS (2 x 1) + 1 = 3 ? CAT

Please tell me now what you would say out loud if you saw this on the screen.

*You can always take as much time as you need to answer "yes" or "no" to the equations that you'll see. If you need to think about it for a moment before you answer, that's fine. It is very important that you always do your best to answer correctly. However, after you say "yes" or "no," you must say the word out loud **IMMEDIATELY**. Please do NOT pause before saying the word out loud.*

After you read the word aloud you'll see a new equation and word appear. Please begin reading the equation aloud as soon as it appears on the screen. Do NOT pause before reading the equation.

We will go through a series of equations and words, with one right after the other, until you see the three question marks appear on the screen.

???

Your job is then to write down all of the words you saw in that set, in the SAME order that you saw them in.

Please write your answers on your answer sheet, going across from left to right. If you can't think of all the words, please leave a blank space for any words you can't remember. There is no penalty for guessing. Every time you recall a different set of words, please write your answer on a new row. Do you have any questions?

Let's begin with some practice, so you can get used to how this task really works. For practice, you can use the very short rows on the top of your answer sheet.

Are you ready to begin the practice?

9 Appendix 3

How to Measure Complex Span Tasks or Working Memory Tasks

As it currently stands, there at least four *different* procedures for scoring dual-task situations (span-measures; see Table 9.2). Concerning the analysis of data (or data sets), the implication is rather serious. For instance, the specific procedure that one decides on will invariably impact (and therefore change) the *rank* order and interpretation of the data.

To illustrate, consider the *R*span task of Daneman and Carpenter (1980). The *R*span comprises 15 items (i.e., groups of sentences), 3 each consisting of two, three, four, five and six sentences. A 2-word item begins the task and continues until accuracy falls below a certain threshold. A *quasi-absolute span score* is then assigned—calculated as the last item size at which the participant could perfectly recall at least 2 out of 3 word items. Along these lines, the assumption is that item size (two, three, four, five, or six) reflects a given 'limit' that "meets a person with a given ability" (Conway et al., 2005, p. 774).

There are, however, two shortcomings with the assignment of a quasi-absolute span score. The first is that quasi-scores limit the range of "span score" values. This limited range (somewhere between 2 and 6) carries with it the loss of potentially useful data and fruitful information (e.g., subsequent "missed" trials), which may thereby reduce the overall sensitivity of the research tool (see Chapter 4).

Second, there is considerable *variability* in the administration of dual-task situations that may influence the *rank order*. For example, in the case of the *R*span, sentences, which are longer in length, should further challenge the performance effectiveness of to-be-remembered words over shorter sentences (see Towse, Hitch, & Hutton, 2002). As well, the (1) display duration (immediate or delayed); (2) stimulus presentation (ascending order or randomised); (3) item size ('2 – 5' or '2 – 6' elements); and (4) semantic similarity of the stimuli, are also factors threatening the rank order (quasi-absolute "span score") of the participant.

In addressing these limitations, Conway et al., (2005) advocate a much simpler scheme. The authors suggest assigning a value *within an item*: a "1" for a correct response (i.e., a "full score") or a "0" for an incorrect response (i.e., a "partial score"), with the requirement that processing accuracy be maintained above 85%.

Following the example of Conway et al., (2005) performance of a fictional participant is provided in Table 9.1. As can be seen, the participant appears challenged even under low loadings (i.e., two-word items for the Operation Span). Looking further down the column, it is also apparent that the participant sometimes scores lower on items with higher loadings than on lower loadings. To help assign a "span score" to the participants' performance, Conway et al. ask two broad questions:

1. Should 'all or nothing' ("full") or partial credit be assigned if some, but not all, elements are recalled?
2. Should a higher weight be assigned for items that have higher loadings (i.e., 3, 4, or 5 elements; unit versus load weighting)?

Table 9.1
Results From Two Complex Span Tasks for a Fictional Participant

Results From Two Complex Span Tasks			
No. of Elements (Set Size)	**Item No.**	**Reading Span (WMc; Set Sizes 2 – 5)**	**Operation Span (WMc; Set Sizes 2 - 5)**
2	1	2	2
	2	2	1
	3	2	2
3	4	3	3
	5	3	3
	6	3	3
4	7	4	1
	8	3	3
	9	4	2
5	10	2	1
	11	4	2
	12	4	2

Note. Each span task has 12 items, made up of 2, 3, 4, and 5 elements (set-size), each with three variations. Each cell represents the absolute number of elements recalled for that item.

Whether to assign a full or partial score requires some forethought. In the case of an 'all or nothing' ("full") score, a value ("1") is assigned only to *completely correct items* (i.e., 2 out of 2 elements). By contrast, a partial score assigns a fraction of value to items where only a portion of elements (1 out of 2) are correct. Considering the fictional scores in Table 4, a full score could *not* be assigned for any of the items with a memory load of "5", whereas a partial score could be (usually as a fraction of "1").

The second question pertains to whether all items ("*n* items") are worth an equal weight, or whether items with higher memory loads (3, 4 or 5 elements) are worth more. If all items are equal ("unit scoring"), then scoring on each item as a *fraction* of correctly recalled items is sufficient. That is, whether a participant scored '1 element from a 2 element item' or '2 elements from a 4 element item' would not matter, both would yield .50. On the other hand, "load scoring" would simply require that the average of all correctly recalled elements be computed, and this irrespective of item size. Along these lines, those items with more elements would contribute more to the overall span score.

Taken together, these two questions strike an interesting paradox. In the most basic sense, the two questions—one concerning full versus partial credit, and one concerning unit versus load weighting—are orthogonal (see Conway et al., 2005). It follows then that four scoring procedures may be conceived (see Table 9.2):

Table 9.2
Illustration of Four Scoring Procedures for Calculating Complex Span Scores

	Results From Two Complex Span Tasks	
Scoring Procedure	**Reading Span (WMc; Set Sizes 2 – 5)**	**Operation Span (WMc; Set Sizes 2 - 5)**
PCU[a]	(1 + 1 + 1 + 1 + 1 + 1 + 1 + .75 + 1 + .4 + .8 + .8) = 10.75/12 = **.90**	(1 + 1 + 1 + 1 + 1 + 1 + .25 + .75 + .5 + .2 + .4 + .4) = 8.5/12 = **.71**
ANU[b]	(1 + 1 + 1 + 1 + 1 + 1 + 1 + 0 + 1 + 0 + 0 + 0) = 8/12 = **.67**	(1 + 0 + 1 + 1 + 1 + 1 + 0 + 0 + 0 + 0 + 0 + 0) = 5/12 = **.42**

PCL[c]		(2 + 2 + 2 + 3 + 3 + 3 + 4 + 3 + 4 + 2 + 4 + 4) = 36/42 = **.86**	(2 + 1 + 2 + 3 + 3 + 3 + 1 + 3 + 2 + 1 + 2 + 2) = 24/42 = **.57**
ANL[d]	(2 + 2 + 2 + 3 + 3 + 3 + 4 + 0 + 4 + 0 + 0 + 0) = 23/42 = **.55**	(2+ 0 + 2 + 3 + 3 + 3 + 0 + 0 + 0 + 0 + 0 + 0) = 10/42 = **.24**	

[a] PCU = Partial Credit Unit Scoring: the mean proportion of elements within an item that were correctly recalled. [b] ANU = All or Nothing Unit Scoring: Proportion of items (*n* items) for which all the elements were correctly recalled. [c] PCL = Partial Credit Load Scoring: the sum of correctly elements from all items. [d] ANL = All or Nothing Load Scoring: the sum of correctly recalled elements from *only* the items in which all elements (2 out of 2, and so forth) were correctly recalled. Note: Results are for the fictitious participant in Table 9.1. Adapted from Conway et al. (2005, p. 775).

Finally, the matter of scoring deserves some attention. According to Conway et al., (2005) the most frequently applied scoring procedure is some form of load-weighted protocol (typically partial-credit; see Ebbinghaus, 1897). According to the authors, there is no real need to assign higher items (those with more elements) with greater weight. Put simply, all items within a WM task—whether 2 elements or 6—are thought to measure the same underlying ability; that is, the ability to maintain attention in the face of ongoing cognition.

To support their claim, Conway et al., (2005) obtained the data of Kane et al., (2004) in the previous year. The authors found that partial-credit scoring had a clear advantage—in terms of internal consistency—over 'all or nothing' ("full") scoring, and within these, the authors found a slight advantage for unit weighted procedures than for load weighted procedures (See Table 9.3). Thus, following the advise of Conway et al., the current paper reports data using the PCU methodology.

Table 9.3
Internal Consistency Scores Reported by Kane et al (2004)

	Internal Consistency for Kane et al (2004)			
Task	**PCU**	**ANU**	**PCL**	**ANL**
Counting Span	.77	.67	.76	.67
Operation Span	.81	.69	.80	.70
Reading Span	.78	.69	.78	.70

Table 6. Table reproduced from Conway et al. (2005, p.776)

10 Appendix 4

<u>TRAINING IN SIMULATED FLIGHT</u>

Trial Flight

Before we begin, please check that you are seated comfortably. You may wish to adjust your seat position [point to lever] or seat belt [point to strap].

Okay, are you ready? [Wait for verbal response or nod].

To your left is a set of headphones. Could you please put them on? Great, can you hear me? [Wait to hear verbal response].

You may be able to tell that there are some subtle breaks in the sound of my voice. This is normal. If you mishear me, or if you require me to repeat something, please just say so [wait for verbal response of nod].

Okay, so as you can see there are a number of controls in front of you. For this task, you will only need to concern yourself with this one [point to control yoke]. You may like to take hold of it? To fly the plane, pull the control yoke toward you to increase elevation [motion for the person to pull the yoke in]; push it in or away from you [motion as if pushing the yoke in] to descend the plane, which will make the nose go down; and then, as you would in a car, steer left [motion for the person to steer left] and right [motion for the person to steer right] to turn the plane.

I should point out that the controls are very sensitive and can LAG. That is to say, you may find the plane takes some time to respond to your movement. This is especially the case if you are making rapid actions. What you will find is that it is best to make slight adjustments or subtle movements as you fly the plane [motion for the person to make small movements in, out, left and right]. Have you any questions at this point [wait for person to respond].

Okay, let's move on. There are two dials I'd like you to pay attention to. This dial is [point to vertical axis] what is called a vertical indicator. When the needle is positioned on the zero it means the plane is flying level. The needle will track your response as you make alterations to your course. If I ask you to ‘descent the plane at 500 ft/min’, you would push the yolk …… [pause, look at the subject and wait for the person to say ‘in’ or some variation of ‘away from me’]. As you push the yoke in, the needle will track toward the lower 5 [point to the ‘5’ mark on the vertical indicator]. Your second dial is this [point to horizontal indicator], your horizontal indicator. When both arrows are lined up at the centre you are flying straight and level. Have you any questions at this point [wait for person to respond].

The same principals apply when turning. If I ask you to bank left [motion the person to steer left] you will notice the little YELLOW arrow will track to the left. These white pointers [point to indicators] will help with your precision. Have you any questions at this point [wait for person to respond].

Okay, you have just received a set of basic instructions. I will now guide you in completing a number of trial tasks. I will be seated inside the plane next to you. Please PRETNED I am not there. You should NOT look at me or attempt to communicate with me. I will not respond. When I do speak, it will ONLY be to instruct you. For the purposes of training, you will do four tasks:

(1) The first task will be to maintain a straight and level course (for 90-seconds).

(2) The second task will be to maintain a constant 20° angle of bank (for 90-seconds). (3) The third task will be reestablishing level flight (for 30-seconds).

(4) The fourth task will be maintaining a rate of descent of 500 Feet Per Min (ft/min), (for 90-seconds).

For each task, you are to hold the position until I direct you otherwise.

If you are ready, I will push the ‘pause’ button to begin.

Primary Flight

This is the main flight task. Your performance will be evaluated [pause, let the statement settle in]. As I mentioned before, the flight task is similar to the one you just did in training. That is to say, your ONLY task is to fly the plane at a constant decent of 500 feet per minute.

This here [point to runway] is the runway. As you do the task, please direct the plane toward it, but do not try to land. At about 30-seconds into the flight, I will play a pre-recorded verbal task that will be fed your head set. It will last approximately the duration of the flight, about seven minutes. You should listen carefully and respond as you did in the practice session. However, if at anytime you mishear a word or your require clarification, let me know. I will pause the recording and verbally repeat the sentence.

Have you any questions at this point [wait for person to respond].

If you are ready, I will push the 'pause' button to begin.

The DWMc task was in English and involved communication as a pre-recording fed into the participant's headset. As with all cockpit communication, this involved subtle but continual disturbances in acoustic noise, as well as the occasional loss in signal (for a fraction of a second). These abrupt breaks would sometimes result in the loss of an essential word, in which case the experimenter would momentarily pause the recording and verbally repeat the sentence. On two occasions did one participant ask to have a 'statement' (element in an item) repeated.

In terms of noise, realistic sound was channelled through a GMA1347 Audio Panel. Specifically, the outer marker frequency was 400 Hz, the middle marker frequency was 1,300 Hz and the inner marker frequency was 3,000 Hz".

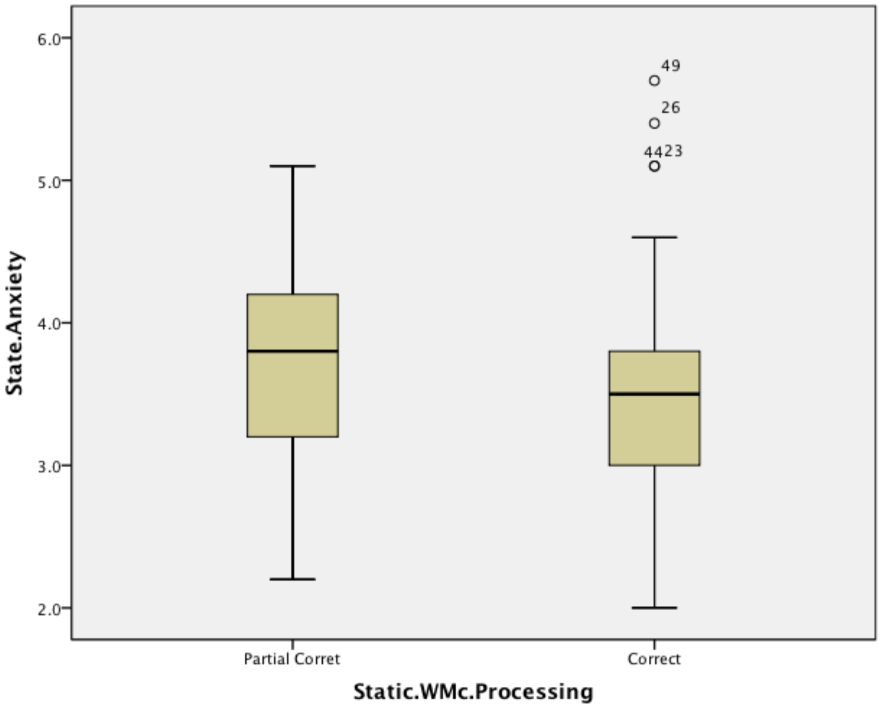
11 Appendix 5

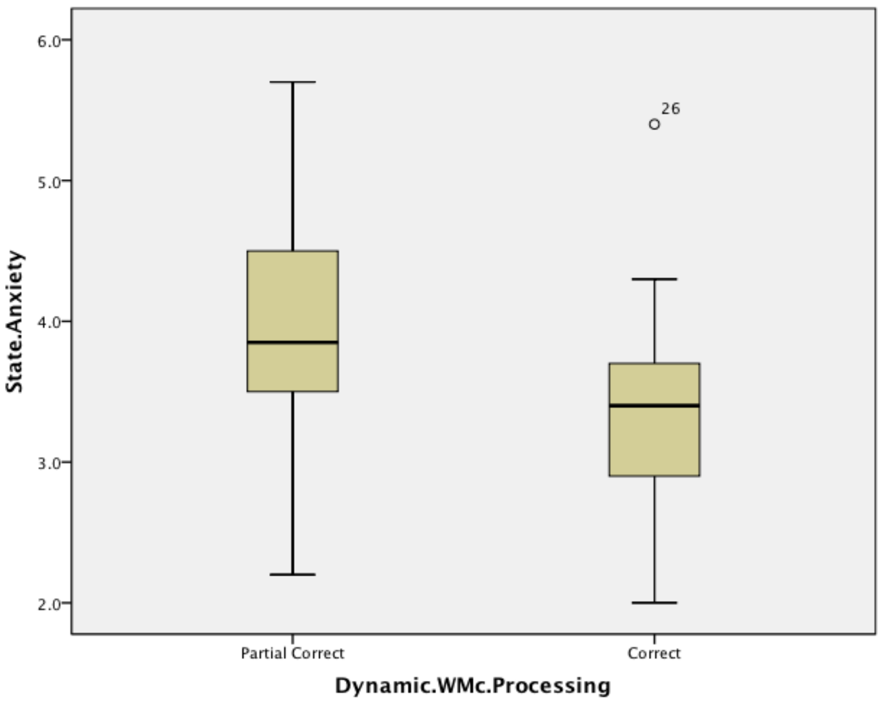
POST-EXPERIMENTAL INTERVIEW

Section 1. Additional information *Remind the participant that their answers are completely confidential and results are reported only in averages so that no one can be identified*	
1. Are you...	Male .... ❑1 Female .... ❑2
2. What is your age in years?	_______________years
3. Approximately how many years have you held a driver's licence? 3a. Approximately how many kilometers do you drive each year?	_______________years _______________km
4. "Have you ever (currently or previously) regularly played simulation games?" Regularly refers to game playing at least once per month. The driving games this question relates to involve vehicle (car, truck) or aircraft control simulation games (i.e., playstation, xbox or arcade games).	Yes .... ❑1 No..................................... ❑2
5. Overall, how would you describe the simulated flight task? Prompt 1. For instance, what words you would use to describe the flight task? Prompt 2. Finish the sentence, "I found the flight task to be …"	______________________________ ______________________________ ______________________________ ______________________________
6. On a scale of 1 to 5, how motivated were you to complete the flight task?	_______________1 to 5
7. Was there significant stress in the flight task? If so, on a scale of 1 to 5, how would you rate the stress? 7.a When you say you were stressed, what does that mean?	_______________Yes or No _______________ 1 to 5 ______________________________
8. On a scale of 1 to 5, how clear where the goals of the flight task.	_______________ 1 to 5

12 Appendix 6

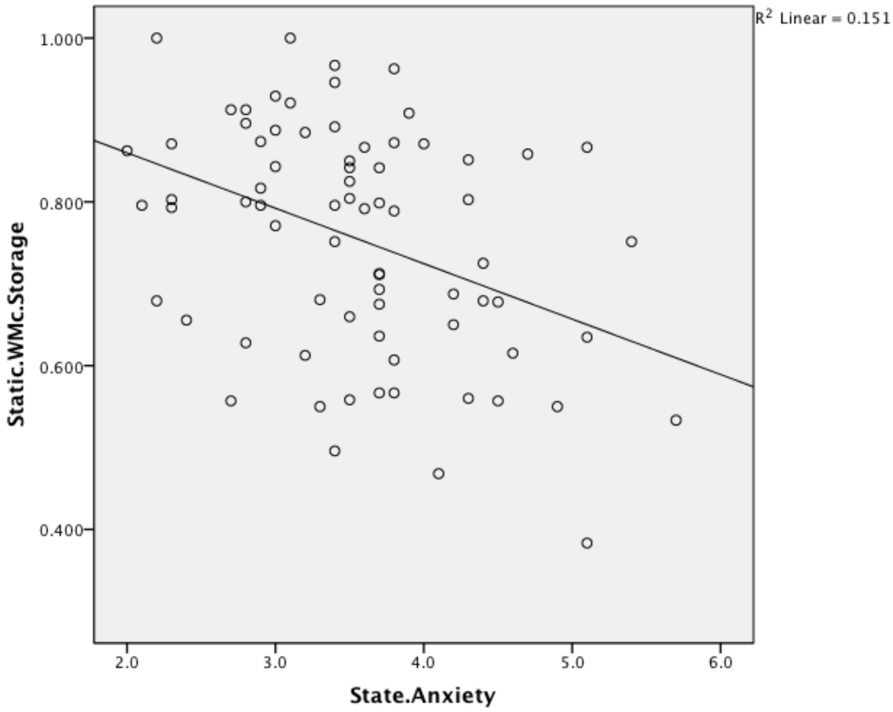
PROCESSING COMPONENT OF WMc - Scatterplots for Static and Dynamic WMc on State Anxiety

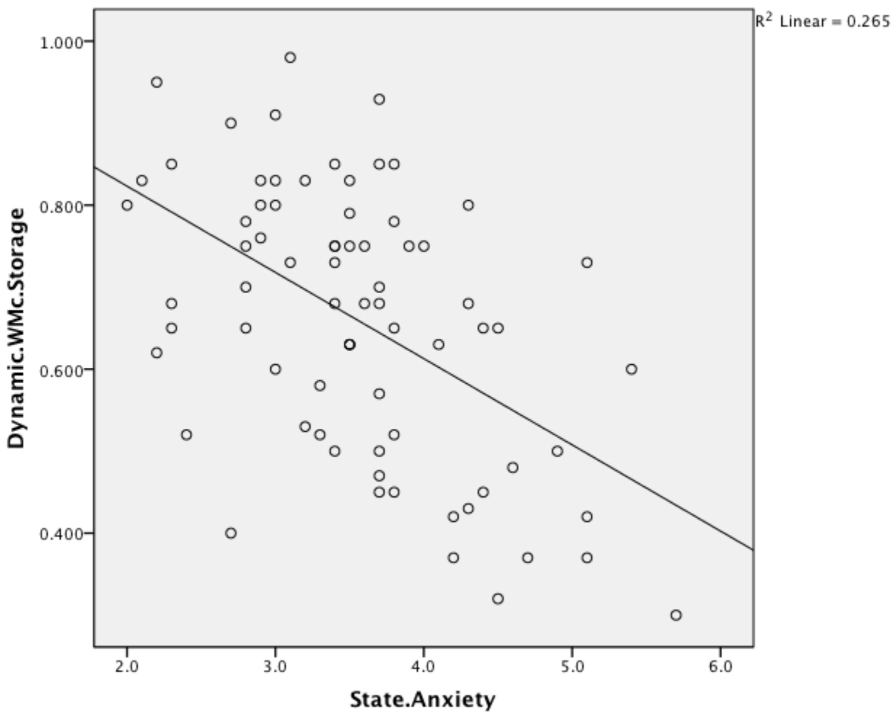




13 Appendix 7

STORAGE COMPONENT OF WMc - Scatterplots for Static and Dynamic WMc on State Anxiety





14 Appendix 8

Descriptive Data for Those with Higher WMc.

Table 14.1

Frequency Table for Descriptive Words Relating to the Divided Attention Task for Those with Low WMc

Descriptive Word(s)	***Tally***	***Frequency (f)***	***Relative Frequency (f/n)***	***Percentage***
Stressful	卌 卌 |||	13	0.116	12
Difficult	卌 卌 ||	12	0.107	11
Self-Conscious	卌 |||	8	0.071	7
Demanding – Cognitively	卌 |	6	0.054	5
Challenging– Cognitively	卌 |	6	0.054	5
Tense	卌 |	6	0.054	5
Too Much to do – Multi-Tasking	卌 |	6	0.054	5
Onerous/Taxing	卌 |	6	0.054	5
Difficult	卌 |	6	0.054	5
Different	卌	5	0.045	4
Nervous/Worrying/Pressure	卌	5	0.045	4
Novel	||||	4	0.036	4
Realistic	||||	4	0.036	4
Draining	||||	4	0.036	4
Concentration	||||	4	0.036	4
Sapping/Tiring/ Exhausting	||||	4	0.036	4
Tedious	|||	3	0.027	3
Unfeasible	|||	3	0.027	3
Unachievable	|	1	0.009	1
Novel	|	1	0.011	1
Processing	|	1	0.011	1
Motion Sickness	|	1	0.009	1
Impossible	|	1	0.009	1
		n = 112	$\Sigma = f / n = 1$	Σ = 100

Descriptive Data for Those with Lower WMc.

Table 14.2

Frequency Table for Descriptive Words Relating to the Divided Attention Task for Those with High WMc

Descriptive Word(s)	***Tally***	***Frequency (f)***	***Relative Frequency (f/n)***	***Percentage***
Challenging	卌 卌 ||	12	0.130	13
New Experience/Novel	卌 卌 ||	12	0.130	13
Demanding – Cognitively	卌 卌	10	0.109	11
Interesting	卌 |||	8	0.087	9
Challenging– Cognitively	卌 ||	7	0.076	8
Effortful	卌 ||	7	0.076	8
Intense	卌 |	6	0.065	7
Manageable	卌	5	0.054	5
Stressful	||||	4	0.043	4
Pressure	|||	3	0.033	3
Realistic	|||	3	0.033	3
Fun/Different	||	2	0.022	2
Practical	|	1	0.011	1
Believable	|	1	0.011	1
Avant-garde	|	1	0.011	1
Involvement	|	1	0.011	1
Tough	|	1	0.011	1
Hard	|	1	0.011	1
Coping	|	1	0.011	1
Mind-Occupied/Multi-Tasking	|	1	0.011	1
Fatigue	|	1	0.011	1
Realistic	|	1	0.011	1
Cool	|	1	0.011	1
Achievable	|	1	0.011	1
		$n = 92$	$\Sigma = f / n = 1$	$\Sigma = 100$

15 Appendix 9

INFORMATION SHEET AND CONSENT FORM (Study 2)

Title: *Trait and State Individual Differences in Working Memory*

You are invited to participate in a study of working memory. The purpose of the study is to examine how individual differences impact working memory in a simulated flight. The study is being conducted by Mr. David Loe, a student of the Master of Organisational Psychology programme at Macquarie University, Sydney. The academic supervisor's of the research are Associate Professor Colin Wastell of the Department of Psychology, Faculty of Human Sciences, and Dr Allan Bull of the Department of Psychology. Their contact details are as follows:

Mr. David Loe (M: 0404 943 181); Associate Professor Colin Wastell (w: 02-9850-8600); and Dr Allan Bull (w: 02-9850-8108)

Upon arrival you will be asked to provide a *unique 6-letter/number code.* If you decide to participate, you will be then given an overview of the experiment, including precautionary medical exclusions:

NOTE: exclusions WILL be made *for participants suffering from heart disease, diabetes, epilepsy, chronic pain or other serious health conditions, in addition to arthritis, a history of frostbite, a rheumatoid condition or Raynaud's disease.* Participation MAY interfere with electronic health equipment and should not be undertaken by persons with pacemakers, heart problems, epilepsy or any other similar or related illness.

Next you will be briefed in the completion of a working memory task, and asked to relax for 3 minutes (during this time you a number of baseline physiological readings will be recorded). Shortly after, you will be introduced to the RedBird FMX Flight Simulator. The simulated flight and working memory task will take about 20 minutes, and includes training in the RedBird FMX Flight Simulator and in the use of a hands free communication device. At the outset, participants will be reminded to always fly carefully and to give priority to the flying task over other tasks. In addition, participants will be required to wear Galvanic Skin Conductors and a Heart Rate Monitor – tools commonly employed in research concerning human factors. The primary task will involve descending at a constant rate of feet per minute and will be concurrent with a secondary working memory task.

Any information or personal details gathered in the course of the study are confidential. No individual will be identified in any publication of the results. The data will be accessed by the persons listed above. If you decide to participate, you are still free to withdraw from further participation in the research at any time without having to give reason and without consequence. Whether you chose to proceed with completing either task or chose not to do so feedback relating to the study will be made available to you.

I, ________________________________ have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to participate in this research, knowing that I can withdraw from further participation in the research at any time without consequences. I have been given a copy of this form to keep.

Participant's Name:
(block letters)

Participant's Signature: ________________________________Date:

Investigator's Name: DAVID LOE
(block letters)

Investigator's Signature: ________________________________Date:

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

16 Appendix 10

TASK INSTRUCTIONS FOR THE DIVIVDED ATTENTION TASK

The divided attention task was adapted in accordance with Baddeley et al.'s (1985) operation of the central executive. In brief, the divided attention task requires the participant to periodically perform a sentence-span task while undertaking a primary flight task. When combined with the flying task, the sentence-span task is thought to place further cognitive load on the aviator.

(i) Sentence-Span Task (Alm and Nilsson, 1994)

The sentence-span task involves two concurrent activities, namely the processing of sentences (i.e., judging of veracity) and the storage (i.e., memorisation and rehearsal) of unrelated words. In the first stage, participants are presented with eight blocks of five sentences (40 in all), some of which are meaningful, of the type "Slippers are sold in pairs", and nonsensical, of the type "Thermometers tell the time". In the second stage, participants are required to recall the last word of each sentence.

(ii) Primary Flight Task

The primary flight task required the participant to maintain a rate of descent of 500 feet per minute (FPM) while keeping the attitude indicator at 0°. Specifications of each simulated flight were preset at a flight level of 5,000 feet in a managed descent mode (vertical speed indicator: 500 fpm), at 80 knots with a bearing of 7 nautical miles toward a runway. Conditions were set to mimic the net effect of mild to moderate turbulence, and the visibility was similar to a clear summer day with a visibility of approximately 5 mile (8.047 kilometres).

17 Appendix 11

PARTIPANT’S DESCRIPTION OF THE DIVIDED ATTENTION TASK

(Study 2; Control Group)

Low Anxious High Working Memory Capacity Group.

Table 17.1

Descriptive Words Relating to the Divided Attention Task for Those with Low Anxiety and High WMc

Descriptive Word(s)	***Tally***	***Frequency (f)***	***Relative Frequency (f/n)***	***Percentage***
Challenging - Cognitively	卌 ||	8	0.15	15
Interesting	卌 |	8	0.15	15
New Experience	卌 |	6	0.11	11
Stressful	卌	6	0.11	11
Fun	||||	5	0.09	9
Exciting	||||	5	0.09	9
Different	||||	4	0.07	7
Challenging - Cognitively	|||	4	0.07	7
Cool	|	4	0.07	7
Original	|	3	0.05	5
Unique	|	2	0.04	4
		$n = 55$	$\Sigma = f / n = 1$	$\Sigma = 100$

Low Anxious Low Working Memory Capacity Group.

Table 17.2

Descriptive Words Relating to the Divided Attention Task for Those with Low Anxiety and Low WMc

Descriptive Word(s)	***Tally***	***Frequency (f)***	***Relative Frequency (f/n)***	***Percentage***
Absorbed	卌 |||	8	0.211	21
Demanding - Cognitively	卌 |	6	0.158	16
Effortful	卌	5	0.132	13
Stressful	||||	4	0.105	11
Challenging - Cognitively	||||	4	0.105	11
Novel	|||	3	0.079	8
Fatigued/Draining	|||	3	0.079	8
Intense	|||	3	0.079	8
Different	||	2	0.053	5
		$n = 38$	$\Sigma = f / n = 1$	$\Sigma = 100$

High Anxious High Working Memory Capacity Group.

Table 17.3

Descriptive Words Relating to the Divided Attention Task for Those with High Anxiety and High WMc

Descriptive Word(s)	***Tally***	***Frequency (f)***	***Relative Frequency (f/n)***	***Percentage***
Stressful	卌 |||	8	0.167	17
Demanding - Cognitively	卌 |||	8	0.167	17
Interesting	卌		6	0.125	13
Concentration	卌	5	0.104	10
Hard	卌	5	0.104	10
Tense	||||	4	0.083	8
Challenging - Cognitively	||||	4	0.083	8
Different	|||	3	0.063	6
Multi-tasking			1	0.021	2
Novel			1	0.021	5
Difficult			1	0.021	2
Pressure			1	0.021	2
Processing			1	0.021	2
		$n = 48$	$\Sigma = f / n = 1$	$\Sigma = 100$

High Anxious Low Working Memory Capacity Group.

Table 17.4

Descriptive Words Relating to the Divided Attention Task for Those with High Anxiety and Low WMc

Descriptive Word(s)	***Tally***	***Frequency (f)***	***Relative Frequency (f/n)***	***Percentage***
Self-Conscious	卌		6	0.143	14
Demanding - Cognitively	卌		6	0.143	14
Challenging - Cognitively	卌	5	0.119	12
Stressful	||||	4	0.095	10
Tiring/Exhausting	||||	4	0.095	10
Impossible	|||	3	0.071	7
Testing	|||	3	0.071	7
Nervous/Excited	|||	3	0.071	7
Intense	||	2	0.048	5
Difficult	||	2	0.048	5
Pressure			1	0.024	2
Draining/Taxing			1	0.024	2
Different			1	0.024	2
Novel			1	0.024	2
		$n = 42$	$\Sigma = f / n = 1$	$\Sigma = 100$

18 Appendix 12

PARTIPANT'S DESCRIPTION OF THE DIVIDED ATTENTION TASK

(Study 2; Experimental Group)

Low Anxious High Working Capacity Group.

Table 18.1
Descriptive Words Relating to the Divided Attention Task for Those with Low Anxiety and High WMc

Descriptive Word(s)	*Tally*	*Frequency (f)*	*Relative Frequency (f/n)*	*Percentage*
Exciting	𝍸 ||||	9	0.150	15
Nervous	𝍸 ||	7	0.117	12
Nerve-Raking	𝍸 ||	7	0.117	12
Challenging - Cognitively	𝍸 ||	7	0.117	12
Interesting	𝍸 ||	7	0.117	12
Stressful	𝍸 |	6	0.100	10
Distracting	||||	4	0.067	7
Testing	||||	4	0.067	7
Hectic	|||	3	0.050	5
Frantic	|||	3	0.050	5
Hair-Raising	||	2	0.033	3
Jittery/Uneasy	|	1	0.017	2
		n = 42	**Σ** = *f* / *n* = *1*	Σ = 100

Low Anxious Low WMc Group.

Table 18.2
Descriptive Words Relating to the Divided Attention Task for Those with Low Anxiety and low WMc

Descriptive Word(s)	*Tally*	*Frequency (f)*	*Relative Frequency (f/n)*	*Percentage*
Demanding - Cognitively	𝍸 ||	7	0.143	14
Exhausting	𝍸 |	6	0.122	12
Self-Conscious	𝍸	5	0.102	10
Strenuous	𝍸	5	0.102	10
Defeated	𝍸	5	0.102	10
Nerve-Racking	||||	4	0.082	8
Stimulating	||||	4	0.082	8
Onerous	||||	4	0.082	8
Concentration	|||	3	0.061	6
Exciting	||	2	0.041	4
Fun	||	2	0.041	4
Confusing	|	1	0.020	2
Interesting	|	1	0.020	2
		n = 49	**Σ** = *f* / *n* = *1*	Σ = 100

High Anxious High Working Memory Capacity Group.

Table 18.3
Descriptive Words Relating to the Divided Attention Task for Those with High Anxiety and High WMc

Descriptive Word(s)	*Tally*	*Frequency (f)*	*Relative Frequency (f/n)*	*Percentage*
Interesting	卌 ||	7	0.152	15
Nerve Raking	卌 |	6	0.130	13
Engaging	卌 |	6	0.130	13
Strained	卌	5	0.109	11
Stressful	卌	5	0.109	11
Concentration	卌	5	0.109	11
Difficult	||||	4	0.087	9
Challenging - Cognitively	||	2	0.043	4
Tense	||	2	0.043	4
Hard - Multi-tasking	||	2	0.043	4
Novel	|	1	0.022	2
Confusing	|	1	0.022	2
		$n = 46$	$\Sigma = f / n = 1$	$\Sigma = 100$

High Anxious Low Working Memory Capacity Group.

Table 18.4
Descriptive Words Relating to the Divided Attention Task for Those with High Anxiety and low WMc

Descriptive Word(s)	*Tally*	*Frequency (f)*	*Relative Frequency (f/n)*	*Percentage*
Self-Conscious	卌 ||||	9	0.14	14
Burdensome	卌 ||	7	0.11	11
Overwhelming	卌 ||	7	0.11	11
Unsettling	卌 ||	7	0.11	11
Stressful	卌 ||	7	0.11	11
Defeating	卌 |	6	0.09	9
Uncontrollable	||||	4	0.06	6
Unmanageable	||||	4	0.06	6
Strained	|||	3	0.05	5
-Racking	|||	3	0.05	5
Strenuous/Onerous	|||	3	0.05	5
Frightening	|||	3	0.045	5
Exhausting/Taxing	||	2	0.030	3
Jittery/Uneasy	|	1	0.015	2
		$n = 66$	$\Sigma = f / n = 1$	$\Sigma = 100$