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FACULTY OF ENVIRONMENTAL AND LIFE SCIENCES

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The Effects of Acute Psychosocial Stress on the Attentional Networks

by

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Thesis for the degree of Doctor of Philosophy

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Abstract

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Acute stress is a pervasive aspect of modern life that is often considered harmful to health and wellbeing. Whilst its potential to alter attention is also well reported (McEwen & Sapolsky, 1995), there is no consensus whether this change is advantageous or detrimental. This programme of work investigated the effects of acute psychosocial stress on aspects of attention that are frequently engaged in many different tasks; the attentional networks. Additionally, the programme examined whether the physiological transformations following acute stress directly influence any changes to attention. In a synthesis of these aims, novel experiments were designed to measure changes to the normal efficiency of three attentional networks, in two discrete periods following stress that broadly reflect the known physiological response: (1) the activation of the Sympathetic Nervous System (0-15 minutes), and (2) the Hypothalamic Pituitary Adrenal (HPA) Axis (20-35 minutes). Self-report measures and biomarkers Alpha Amylase (SNS) and Cortisol (HPA-Axis) confirmed successful stress induction following a Socially Evaluative Cold Pressor Task. Behavioural data showed that whilst exposure to acute stress can lead to heightened levels of vigilance, it can also suppress practice effects impacting on executive control of attention. Moreover, these effects manifest differently depending on the time of day. When measured in the morning, the effects appear dependent on the time course of stress, with hypervigilance evident immediately following exposure, and practice suppressed in the delayed period. However, in the afternoon, such effects did not appear to be moderated by time-course and appeared irrespective of period. Alpha Amylase and Cortisol were further examined to understand whether elevated levels of the biomarkers predicted those changes to attention. Elevated SNS activity (Alpha Amylase) was related to heightened vigilance in the morning. However, in spite of its prominence across stress literature, Cortisol did not appear to share a relationship with any change to attentional efficiency.

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Research Thesis: Declaration of Authorship

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I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

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2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
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7. None of this work has been published before submission

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Definitions and Abbreviations

ANOVA	Analysis of variance – a statistical test.
ANT(-R)	Attentional Network Test (-Revised)
CITS-S	Coping Inventory for Task Stress - Situational
CPT	Cold Pressor Task
CTOA	Cue-to-Target Onset Asynchrony
CV	Coefficient of Variation
EEG	Electroencephalography
ERP	Event Related Potentials
HPA-Axis	Hypothalamic Pituitary Adrenal Axis
HUET	Helicopter Underwater Evacuation Training
IUS (-12)	Intolerance of Uncertainty (-12) refers to IUS scale
MEG	Magnetoencephalography
MIST	Montreal Imaging Stress Task
NASA-TLX	National Aeronautics and Space Administration-Task Load Index
NHS	National Health Service
OSPAN	Operational Span Task
PFC	Pre Frontal Cortex
PNS	Parasympathetic Nervous System
PVT	Psychomotor Vigilance Task
RAVLT	Reys Auditory Verbal Learning Test
RT(s)	Response / Reaction Times
sAA	Salivary Alpha (α) Amylase
SART	Sustained Attention to Response Task
sCortisol	Salivary Cortisol
SD	Standard Deviation
SECPT	Socially Evaluative Cold Pressor Task
SNS	Sympathetic Nervous System
SSAI	Spielberger State Anxiety Index
STAI	Spielberger Trait Anxiety Index
TSST	Trier Social Stress Test
WM(C)	Working Memory (Capacity)

1 Introduction

1.1 What is Stress?

Throughout human existence, stress has been a feature of a person's daily experience (Hancock & Szalma, 2008). What was once the physical threat of predators and environmental change, evolved into the psychological "stresses of combat" during the First and Second World Wars (Grinker & Spiegel, 1945). Nowadays, the greatest threat of daily stress seems likely to come from work demands, quarrels with loved ones, or financial insecurities. Constant throughout this evolution is the potential for stress to significantly impact on an individuals' daily life, health and their psychological wellbeing (Bolger, DeLongis, Kessler, & Schilling, 1989; Lupien, McEwen, Gunnar, & Heim, 2009).

The purpose of the current research is to examine the effects of acute stress on cognition, specifically attention. However, this is only one of three distinct characterisations of stress that exist in the psychological literature: 'acute', 'episodic acute' and 'chronic'. According to the American Psychological Association, the most common of these forms is acute stress. Acute stress arises "from demands and pressures of the recent past and anticipated demands and pressures of the near future" and is largely distinguishable by its short term impact ("Stress: The different kinds of stress.," 2016). Episodic acute stress can be considered as an extension to this; it is borne out of a perpetual predisposition to disorder, worry and pressure. Sufferers of episodic acute stress identify stressful elements in most aspects of everyday life, therefore experiencing particularly high exposure to acute stress. When an individual experiences acute stress, their body initiates a physiological response, engaging their Sympathetic Nervous System (SNS) and the Hypothalamic Pituitary Adrenal Axis (HPA-Axis), preparing their body to deal with the situation before returning them to a state of homeostasis as quickly as possible.

On the other hand, chronic stress is regarded as an unrelenting state of stress, persisting over an "interminable period[s] of time" and which can be both "psychologically and physically debilitating" ("Understanding chronic stress.," 2016). Chronic stress wears an individual down through attrition, leaving them unable to see an end to the situation in which they find themselves. It has also been linked to an enormous amount of adverse short- and long-term health problems and psychological issues (G. E. Miller, Chen, & Zhou, 2007). These include a susceptibility to eating disorders and obesity (Torres & Nowson, 2007), anxiety and depression (Kendler, Karkowski, & Prescott, 1999; Surtees et al., 1986), poorer immune response (Kiecolt-glaser, Glasert, Gravenstein, Malarkey, & Sheridan, 1996; Segerstrom & Miller, 2004) and coronary heart disease (Esch, Stefano, Fricchione, & Benson, 2002; Steptoe & Kivimäki, 2012).

The effect of chronic stress on cognition is less established, possibly due to the difficulty in tracking its pathology independent of confounding factors such as other medical disorders (e.g. Chronic Fatigue Syndrome - Öhman, Nordin, Bergdahl, Slunga Birgander, & Stigsdotter Neely, 2007). The relatively limited number of cognitive changes (in humans) that have been reported include sub-optimal attentional control and impaired prospective memory (Öhman et al., 2007), working memory, speed of executive control, learning and episodic memory (Jonsdottir et al., 2013) and inhibitory control (Marshall, Cooper, & Geeraert, 2016).

In contrast to chronic stress, the impact of acute stress on general health appears limited to relatively minor concerns such as irritable bowel syndrome and inflammation (Steptoe, Hamer, & Chida, 2007). More severe conditions have been reported, such as hypertension and cardiovascular issues. However such reports tend to be limited to the most extreme instances of acute stress, for instance following acts of terrorism (Holman et al., 2008 - in the wake of the attacks on the World Trade Center, New York).

There has however, been several decades' worth of investigation examining the influence that exposure to acute stress can exert upon cognition, with it widely-accepted

that acute stress exposure can often lead to noticeable deviations in normal cognitive function (McEwen & Sapolsky, 1995). Indeed, in some of the more serious instances of acute stress, whole aspects of cognition can fail entirely, leading to cognitive paralysis (Leach, 2005; see also 'Gothenberg fire' cited in Robinson, Leach, Owen-Lynch, & Sünram-Lea, 2013). Despite appreciation that stress possesses the potential to influence cognition, there is a conspicuous lack of consensus concerning the types of cognition affected and how; or of any comprehensive framework that is able to accurately conceptualise or predict the effects of stress.

1.2 The Models of Stress

A common misconception of stress is that its effects are limited to negatively influencing individuals. Literature has shown, that on occasion, exposure to a stressful encounter can achieve positive, adaptive changes (Hancock & Szalma, 2008). Desire for a clearer understanding of the negative consequences of stress, as well as the prospect of harnessing any potential benefits, has driven researchers to study stress as a psychological concept intently since the mid-20th century (Hancock & Warm, 2003). Nevertheless, the endeavour has not been without its difficulties. As a result of such intense scrutiny, Stokes and Kite (1994) asserted that as a scientific concept, stress had fallen foul of the "numerous applications of the term" both within, and outside of Psychology, leading to its diminished effectiveness as a psychological concept. However, interest in stress research endures across psychological literature, with contemporary psychologists conceptualising it as a state of real or perceived threat to homeostasis, resulting from an individual's environment (Schlotz, Yim, Zoccola, Jansen, & Schulz, 2011; Smith & Vale, 2006).

1.2.1 Early Models

Early stress models focused on the type of stress and the change it enacted within an individual; so called Stimulus-Response (S-R) models (Selye, 1950). One theory that was initially popular was "Arousal Theory". Arousal, described as the "basic energetic

state of an organism" (Stokes & Kite, 1994, p.113), was one of the first constructs to be associated with performance under stress. The theory developed out of work undertaken at the beginning of the 20th century by Yerkes and Dodson (1908), and states that alteration to levels of arousal is what "mobilises and regulates the human stress response" and their subsequent performance (Staal, 2004).

In their original work, Yerkes and Dodson examined the effect of electric shocks on mice learning to discriminate between two routes. The authors reported that when the mice were subjected to electric shocks for selecting an incorrect route, they learned to take the correct route quicker. Furthermore, their speed of learning (number of attempts) improved in line with the strength of the shock, up to an optimal point before deteriorating. Although Yerkes and Dodson themselves never concluded that stress led to arousal and consequent changes in performance, many authors interpreted it as such, and used it as the foundation for their subsequent work (Broadhurst, 1957; Brookhuis & de Waard, 2001; Duffy, 1957; Easterbrook, 1959; Selye, 1956). Initially using rodents in their experiments before evolving to human subjects, the researchers attested that moderate levels of arousal, often conceptualised as stress, resulted in peak performance whilst under- or over-arousal worsened performance. The finding was detailed as a curvilinear relationship and termed the 'inverted U'.

The 'inverted U' theory was prevalent for several decades, despite the lack of any definition as to what constituted under- or over-arousal, or what an "optimum" level might be. Although inadequate as a theory, it most likely endured due to its commonality with another arousal/activation theory proposed by Duffy (1941), who stated that "the optimal degree of activation appears to be a moderate one" (Duffy, 1957). Additionally, another competing theory of the time – Drive Theory – which instead proposed a positive linear relationship lacked any substantial empirical support (Hull, 1943; Spence, 1951). Over time the 'inverted-U' theory fell out of favour as a result of multiple studies failing to replicate the original findings (Banich, Stokes, & Elledge, 1988; Stokes & Kite, 1994),

whilst others suggested that moderate electric shocks failed to invoke any level of arousal (Hancock & Ganey, 2003).

1.2.2 Resource Models

One theory that has linked arousal to performance under stress is Resource Theory; often credited to Kahneman (1973). Kahneman suggested that when attempting to complete tasks, individuals draw upon a pool of mental resources, and that the level of resources available was dependent upon the state of arousal of the individual. Additionally, Kahneman proposed that task difficulty was dictated by the level of effort required. Therefore, performance was likely to be significantly poorer when individuals failed to appraise situations appropriately, as they would have less resources available to allocate. This view was supported more recently by Fairclough (2001) who asserted that under conditions of stress, appraisal of a task and its demands is likely to be poorer, resulting in a shortfall of available resources. Some research has offered support for this view, including Gopher and Braune (1984) who reported that the resources a person invested in a task increased with task difficulty. However, the theory is not without its detractors with some arguing that it is overly simplistic, there likely being more than a single pool of cognitive resources to draw upon (Marsh, Hicks, & Cook, 2004). Others have instead argued against the notion of a general "resource pool" (Allport, 1980). Although perhaps most importantly, many of the claims made by Resource Theory have proven difficult to validate empirically (Navon, 1984).

1.2.3 Transactional Models

Evolving from the Stimulus-Response models, investigations between the 1950's and 1970's began to emphasise the importance of individual differences in addition to situational appraisals like Kahneman. This evolving perspective transitioned to more inclusive Stimulus-Organism-Response (S-O-R) type models or "Transactional models". Some of these models built directly on the arousal theory of stress, with links to motivation

(Welford, 1973), internal activation (Pribram & McGuinness, 1975), and most recently a transactional view incorporating cognitive appraisal (Hancock & Warm, 2003). Many of these models have also evolved more comprehensive definitions of stress, describing it as the introduction of a novel situation that one appraises as exceeding one's ability to cope, or that threatens wellbeing (Lazarus, 1966; Lazarus & Folkman, 1984). McGrath (1976) argued there may also be an external pressure that the individual is expected to have the skills to adequately cope with the demand. Most recently, Koolhaas et al. (2011) asserted that stress can be reasonably defined, yet sensibly constrained as a situation that is experienced unpredictably, and appraised as uncontrollable.

Respecting these definitions, Transactional models have proven popular, with many studies demonstrating that cognitive appraisal is not only necessary, but an important element in performance under stress, as threat evaluation or controllability exhibits a close relationship with subjective experiences of stress (for review see Staal, 2004). Transactional models not only remain relevant, but are continuously evolving (Lazarus, 1966, 1993; Lazarus & Folkman, 1987; Woodworth, 1958), with contemporary studies consistently finding significant support for the effect of appraisal and individual differences on human performance under stress (Duckworth, Bargh, Garcia, & Chaiken, 2002; Hoskin, Hunter, & Woodruff, 2014; Schupp, Junghöfer, Weike, & Hamm, 2003). As an example, Matthews (2001) used a series of driving simulator studies to develop a transactional model that implicates not only appraisal of a situation, but also the selection of an appropriate coping mechanism.

Models incorporating transactional concepts often also promote evaluative reflexes such as; 1) negative bias, e.g. Crawford and Cacioppo (2002), who argued that humans are primed to evaluate their environment, and that anything evoking negative affect is likely to manifest differently to non-affective experiences; 2) predictability and controllability, e.g. Monat, Averill, and Lazarus (1972), who found that threatening stimuli that are predictable cause less aversive change than threatening stimuli that are

unexpected; 3) biological responses, e.g., Biondi and Picardi (1999), who reported that subjective perception of a situation modified endocrine response and therefore performance. For these reasons, many contemporary studies researching stress endeavour to not only initiate unpredictable environmental change, but also account for individual differences in appraisal, bias and physiological responses.

In summary, whilst initial research favoured simple escalation of arousal levels as the principal component responsible for the effect of stress on task performance, the narrative has matured. Instead, the importance of the individual's psychological assessment, including their appraisal of both the situation and their ability to cope is recognised, as well as how they allocate resources and their physiological reaction. However, a theory that is able to comprehensively explain why, and predict how stress affects performance is still yet to be realised.

1.3 The Effects of Acute Stress on Cognition

While the effects of acute stress on general health appear limited, a large body of research has examined how it can affect various aspects of cognition, both in the moment and for short periods afterwards. The results of such examination are confusing at best, and contradictory at worst, with a distinct lack of clarity as to what is improved and what is impaired by exposure, across all manners of cognition. (See Table 1.1 for a summary of these studies.)

1.3.1 Memory

One aspect of cognition commonly investigated with regard to stress is memory, where several researchers have reported improved performance. For instance, Buchanan and Lovallo (2001) reported that recall for emotionally salient pictures was enhanced following a pharmacological simulation of stress (participants administered Cortisol). A later study found that emotionally valent words were recalled more successfully following exposure to an acute psychosocial stressor (Jelicic, Geraerts, Merckelbach, & Guerrieri,

2004). Jelicic et al. (2004) also reported impairment of emotionally neutral words, highlighting individuals' evaluative reflexes (i.e. negative bias), a finding supported by several others (Kirschbaum, Wolf, May, Wippich, & Hellhammer, 1996; Tops et al., 2003). However, as if to underline the contradictory nature of the literature, a later study by Jelicic and colleagues failed to demonstrate any differences to recall of emotionally valent words (Smeets et al., 2006). One possible explanation offered for this difference was the absence of any perceptible changes to Cortisol level amongst "stress" participants in the earlier study, implicating an individual's physiological response. This will be discussed in greater detail later.

Further research has shown that spatial memory can be enhanced by exposure to stress. Luethi, Meier, and Sandi (2009) examined spatial memory recall for various map routes and reported that route recall was significantly improved following exposure to a psychosocial stress procedure. This contradicted earlier work that reported spatial memory was impaired following stress (predominantly animal studies, although see Newcomer et al., 1999). Most notably, Luethi and colleagues demonstrated that recall of information other than that which was emotionally salient, could be improved under conditions of acute stress.

Gagnon and Wagner (2016) offered some important insight, suggesting that it is not only the type of cognitive function being accessed that is important, but how that function is being utilised. In the context of memory, they asserted that whilst encoding of information is usually improved by stress, retrieval is often appreciably weaker. This latter point has been supported by several studies that have demonstrated the effect of stress on memory is not always positive. For instance, Domes, Heinrichs, Rimmele, Reichwald, and Hautzinger (2004) employed the Trier Social Stress Test (TSST – Kirschbaum, Pirke, & Hellhammer, 1993), a popular psychosocial stressor where participants are expected to perform a free speech in front of a judgemental panel and then complete a difficult and prolonged mental arithmetic task. Following the TSST, memory was tested using a word

recall task. The authors observed poorer recognition for positive words, but only if subjects were stressed prior to retrieval and not prior to learning the wordlist (i.e. encoding). Additionally, the results indicated that increased levels of Cortisol, associated with stress induction shared a positive correlation with errors of commission, or false memories.

Contrary to Buchanan and Lovallo (2001) and Jelicic et al. (2004) reviewed earlier, Domes et al. (2004) failed to demonstrate any enhancing effects of stress towards recall of emotionally valent material. Instead, they reported that positive words were retrieved significantly less often than neutral or negative words following acute psychosocial stress. Other studies that have employed the TSST have also demonstrated significant stress-induced impairments in memory, including declarative memory amongst older adults (Hidalgo, Almela, Villada, & Salvador, 2014), free recall in women, younger males and children (Almela et al., 2011; Hidalgo et al., 2015; Quesada, Wiemers, Schoofs, & Wolf, 2012) and positive image recognition (Guez, Saar-Ashkenazy, Keha, & Tiferet-Dweck, 2016; Hidalgo et al., 2015).

These effects have been further explored and consolidated when considering alternative types of stressors, such as fire-fighting exercises (Robinson et al., 2013), examination periods (Hoorelbeke, Koster, Vanderhasselt, & Callewaert, 2015; Lewis, Nikolova, Chang, & Weekes, 2008), routine daily stressors (measured via diary completion - Neupert, Almeida, Mroczek, & Spiro III, 2006), as well as the commonly used Cold Pressor (CPT) and Socially Evaluative Cold Pressor Tasks (SECPT) (Glienke & Piefke, 2016; Ishizuka, Hillier, & Beversdorf, 2007; Schoofs, Wolf, & Smeets, 2009). In both the CPT and SECPT, participants are required to immerse their hand in ice-cold water for a short period of the time. The SECPT additionally leads the participants to believe their experience is being video-recorded for comparison to their peers in order to exert additional psychological stress. Both the CPT and SECPT have been well-validated in

laboratory studies (Schoofs et al., 2009; Schwabe, Haddad, & Schachinger, 2008; van Stegeren, Wolf, & Kindt, 2008).

1.3.2 Attention

In addition to memory, specific aspects of attention have been shown to improve following acute stress exposure, such as selective attention. Dandeneau, Baldwin, Baccus, Sakellaropoulo and Pruessner (2007) found participants who had undertaken a time-pressured mental arithmetic task (the Montreal Imaging Stress Task - MIST) demonstrated a selective attentional bias to negative images (rejecting-type faces) in a visual probe task. An influential article by Chajut and Algom (2003) employed a particularly large sample to examine selective visual attention, operationalised using various Stroop paradigms (Stroop, 1935) with Garner interference[1]. In Chajut and Algom's work, the authors exposed half the group to a variety of stressors such as time pressures, task difficulty, and socially-evaluative threats, and found that under conditions of low stress, Garner interference was reported as expected, slowing participants response times (RT) by 19 ms. In contrast, under conditions of high stress, this interference effect was significantly reduced. This demonstrated that under conditions of high acute stress, participants were able to successfully withstand intrusions from task irrelevant stimuli, thus suggesting a narrowing of attention that allowed the subject to focus attention directly toward the target stimulus.

1.3.3 Executive Functions

Other executive functions have undergone scrutiny, such as decision making and cognitive flexibility. In one example, decision making was shown to be impacted by acute psychosocial stress (TSST) as stressed participants demonstrated riskier behaviour than controls, even when they had been informed about the resulting unfavourable

[1] Garner interference describes the phenomenon whereby a second, irrelevant, yet related dimension to that being assessed, causes interference as the participant cannot separate the two dimensions as well as if they were unrelated (Zakay, Bibi, & Algom, 2014).

consequences (Starcke, Wolf, Markowitsch, & Brand, 2008). Additionally cognitive flexibility, important for adjusting to situational demands, was reduced significantly following exposure to the same psychosocial stress, likely as a result of increased goal-shielding (Plessow, Fischer, Kirschbaum, & Goschke, 2011; Plessow, Kiesel, & Kirschbaum, 2012).

There has also been a keen interest in the effect of stress on working memory, using both laboratory stress paradigms (Schoofs, Preuß, & Wolf, 2008; Schoofs et al., 2009) and more naturalistic environments such as examination periods (Lewis et al., 2008), Helicopter Underwater Evacuation Training (HUET - Robinson, Sünram-Lea, Leach, & Owen-Lynch, 2008), parachuting (Leach & Griffith, 2008) and fire-fighting (Robinson et al., 2013). Much of the research has shown that acute stress exposure is able to exert a negative influence on working memory (Shields, Sazma, & Yonelinas, 2016). These effects have been demonstrated extensively across a variety of working memory dimensions, including reading span (Luethi et al., 2009), digit span (Duncko, Johnson, Merikangas, & Grillon, 2009) and spatial working memory (Olver, Pinney, Maruff, & Norman, 2015).

Conversely, other work has found improvements to aspects of working memory under stress. In an fMRI study, acute psychosocial stress initiated by the TSST was reported to have not only increased the neuroendocrine response to stress, but also to have improved working memory accuracy (Weerda, Muehlhan, Wolf, & Thiel, 2010). Similar effects have been demonstrated when using alternative psychosocial stressors such as the Cold Pressor task, where the subsequent increase in arousal has been linked to improved working memory efficiency (speeded response times) in an item recognition task (Duncko et al., 2009). One particularly interesting result was reported by Zandara et al. (2016) who demonstrated that working memory can be improved following stress exposure if the experience is suitably appraised and adequately coped with, thus reinforcing Matthews transactional model of stress (Matthews, 2001). In Zandara's study, a significant number

of female participants who were exposed to acute psychosocial stress (TSST) demonstrated improvements to their working memory performance, relative to males and other females. However, this improvement was only observed amongst females who reported more adaptive cognitive threat appraisal (i.e. appraised the situation as either non-stressful, or manageable) and demonstrated reduced Cortisol reactivity in response to the stressor. Although, it is important to note here that the authors allied threat appraisal with reduced neuroendocrine activity, when another possibility is that the females in question did not find the experience as stressful, perhaps due to previous experience.

Clearly, the literature examining the impact of stress on working memory appears to be as conflicted as other types of cognition. However, the literature also highlights the temporal effects of stress. Whilst a number of studies have shown that working memory is affected in the immediate aftermath of exposure to stress (Robinson et al., 2008) or for a maximum of 30-minutes post-stressor (Olver et al., 2015), others have reported that changes are not even initiated for at least the first 20 minutes (Robinson et al., 2013). These findings highlight an important factor which is the time course of any reaction to stress exposure and how this might influence cognitive change. This will be discussed later in this review.

The above studies reflect one aspect of the inconsistent nature of stress research; where the results of similar experiments often directly contradict each other. However, another challenge is studies reporting both positive and negative effects. One example comes from Luethi et al. (2009) who reported a series of contradictory findings. Following exposure to the TSST, participants demonstrated no differences in explicit memory but working memory reading span was significantly poorer. Remarkably however, spatial working memory, as measured by performance in a map navigation exercise, was significantly enhanced. Similar findings have been reported by Duncko and colleagues, who reported that as some participants exhibited beneficial changes to working memory following stress, such as speeded response times, there was also a trade off with accuracy

whereby the rate of false alarms significantly increased (Duncko et al., 2009). Additionally, Vedhara, Hyde, Gilchrist, Tytherleigh and Plummer (2000) reported that throughout periods of high stress, participants were able to maintain verbal working memory performance in an auditory task, though it also resulted in significant degradation to attention and changes to memory which showed a reduced primacy effect.

Other studies that used more naturalistic models such as a simulated fire-fighting emergency, have also demonstrated similar paradoxical effects (Robinson et al., 2013). In their study, Robinson and colleagues found that following completion of the fire-fighting exercise participants demonstrated detriments to working memory performance, whilst selective visual search skills were preserved. This particular finding suggests that these contradictory changes to cognition following stress exposure are not simply limited to the laboratory but also manifest in more representative tasks and importantly, in real-life situations.

Several explanations have been proposed for the negative effect that stress can have on different aspects of cognition. Darke (1988) suggested that an increase in levels of worry and anxiety resulting from stress might hijack limited storage resource and processing capacity and potentially lead to inefficient working memory capacity and impaired cognition. This argument is supported by reports that stress is able to significantly impair working memory at higher loads as opposed to low loads (Oei, Everaerd, Elzinga, van Well, & Bermond, 2006). An alternative view, proffered by Qin, Hermans, van Marle, Luo, and Fernández (2009), is that reduced activity in the dorsolateral prefrontal cortex during stress exposure leads to a significant reduction in the capacity of working memory. This is a popular claim as it not only offers an explanation for (working) memory dysfunction under stress but also deviations in attentional performance which is associated with the prefrontal cortex area of the brain (for reviews of attention dysfunction see Miller & Cohen, 2001; Schall, 2002).

Table 1.1 *A summary of studies that examined the effect of stress on cognition.*

Authors	Year	Method	Type(s) of Cognition Examined	Stressor / Type / Duration	Results
Almela, Hidalgo, Villada, Espín, Gomez-Amor & Salvador	2011	Participants completed the TSST before undergoing a standardized memory test (Reys Auditory Verbal Learning Test - RAVLT).	Memory	TSST PS / SE 20 minutes	Recall of words following interference deteriorated in women post-stress.
Buchanan & Lovallo	2001	Participants administered Cortisol (20mg) or placebo before testing incidental picture memory (one week later).	Memory	Administered Cortisol Pharmacological n/a	Recall of emotionally salient pictures enhanced following administration of Cortisol.
Chajut & Algom	2003	Participants took part in a range of 'Stroop'-style tasks following various stressors including time pressure, task difficulty and social evaluation.	Selective Attention	Timed arithmetic tasks (+ ego threat) Cog. Overload 10 minutes	High stress helped participants ignore irrelevant stimuli, reducing garner interference.
Dandeneau, Baldwin, Baccus, Sakellaropoulo & Pruessner	2007	Multiple experiments were participants completed the MIST, before being tested for selective attention and vigilance.	Selective Attention	Montreal Imaging Stress Task Aversive Stimuli Runs of 6 minutes	Stress led to an attentional bias toward negative images (faces).
Domes, Heinrichs, Rimmele, Reichwald & Hautzinger	2004	Participants completed the TSST either before learning a wordlist, or before retrieval (or were not stressed). Free recall and recognition tested.	Memory	TSST Public Speaking 20 minutes	Poorer recall of 'positive' words when stressed prior to retrieval. Cortisol was also linked to commission errors.
Duncko, Johnson, Merikangas & Grillon	2009	Participants completed CPT before testing their Working Memory (WM) performance.	Working Memory	CPT Environmental 3 minutes	Stress led to shorter RTs but also significantly more false alarms.

Glienke & Piefke	2016	Participants completed SECPT before testing their prospective memory performance.	Memory	SECPT PS / SE 3 minutes	Stress resulted in improved prospective memory.
Guez, Saar-Ashkenazy, Keha & Tiferet-Dweck	2016	Participants completed TSST before testing their 'item' and 'associative' recognition of words/pictures.	Memory	TSST PS / SE 20 minutes	Recall for both words and pictures was impaired following TSST.
Hidalgo, Almela, Villada & Salvador	2014	Participants completed the TSST before undergoing a standardized memory test (RAVLT).	Memory	TSST PS / SE 20 minutes	Recall of words following interference deteriorated in older adults' post-stress.
Hidalgo, Pulopulos, Pui-Perez, Espín, Gomez-Amor & Salvador	2015	Participants completed the TSST before testing their memory recall of emotional pictures.	Memory	TSST PS / SE 20 minutes	Recall poorer for positive pictures. (Recall also poorer in young males for negative pictures).
Ishizuka, Hillier & Beversdorf	2007	Participants completed the CPT before their memory and cognitive flexibility was tested.	Memory and Cognitive Flexibility	CPT Environmental 3 minutes	Memory was impaired but cognitive flexibility was unaffected.
Jelicic, Geraerts, Merckelbach & Guerrieri	2004	Participants completed the TSST before their memory was tested (emotional words).	Memory	TSST PS / SE 20 minutes	Recall of emotional words was enhanced, whereas neutral words were impaired.
Kirschbaum, Wolf, May, Wippich & Hellhammer	1996	Participants completed the TSST before their declarative memory was tested.	Memory	TSST PS / SE 20 minutes	Declarative memory significantly poorer following stress. 10 mg Cortisol led to poorer declarative memory and spatial thinking but not procedural memory.
Leach & Griffith	2008	Participants WM was tested immediately prior to a parachute jump.	Working Memory	Skydiving Naturalistic 10 minutes	Stressed individuals (novices) showed limited WM capacity.
Lewis, Nikolova, Change & Weekes	2008	Participants digit span performance was tested during low stress and high stress (exam) periods.	Working Memory	Exam period Naturalistic Extended - Exam days	During high stress periods, participants digit span (backwards) performance improved.

Luethi, Meier & Sandi	2009	Participants completed the TSST before their explicit and WM performance were tested.	Explicit Memory and Working Memory	TSST PS / SE 20 minutes	WM was significantly poorer following stress. Stress also improved spatial explicit memory.
Neupert, Almeida, Mroczek & Spiro III	2006	Participants completed a 'daily stressors diary' which was then matched to memory failures.	Memory	Daily stressors Naturalistic Various	On days when people experienced more stress, they were more likely to report memory failures.
Newcomer, Selke, Melson, Hershey, Craft, Richards & Alderson	1999	Participants were administered 40 mg/d or 160 mg/d of Cortisol over four days before completing a battery of cognitive tasks.	Memory, WM and Executive Function	Administered Cortisol Pharmacological n/a	Higher doses of Cortisol led to poorer declarative memory but did not impact WM or Executive function.
Olver, Pinney, Maruff & Norman	2015	Participants completed the TSST before completing a neuropsychology battery including spatial WM and verbal memory.	Working Memory, Memory and Attention	TSST PS / SE 20 minutes	Stress impaired delayed verbal recall, attention and spatial WM.
Plessow, Fischer, Kirschbaum & Goschke	2011	Participants completed the TSST before being tested for dynamic control adjustments.	Cognitive Flexibility	TSST PS / SE 20 minutes	Stress led to increased goal shielding but did not impact cognitive flexibility.
Plessow, Kiesel & Kirschbaum	2012	Participants completed the TSST before completing a task switching test to measure cognitive control and flexible task-goal implementation.	Cognitive Flexibility	TSST PS / SE 20 minutes	Stress led to larger performance differences following switches and repetitions, impairing goal-directed behaviour.
Quesada, Wiemers, Schoofs & Wolf	2012	Participants (children) completed the TSST (- for children) before their memory retrieval and WM was examined.	Memory and Working Memory	TSST(-C) PS / SE 20 minutes	Stress resulted in poorer delayed memory retrieval but exhibited no effect on WM.
Robinson, Leach, Owen-Lynch & Sünram-Lea	2013	Participants completed a simulated fire-fighting emergency before completing a neurocognitive battery.	Attention, Memory and Working Memory	Fire-fighting Naturalistic 2 hours	Visual declarative memory was poorer immediately post-stress, WM was poorer after a 20-minute delay.

Robinson, Sünram-Lea, Leach & Owen-Lynch	2008	Participants completed Helicopter Underwater Evacuation Training (HUET) before their WM performance was tested.	Working Memory	HUET Naturalistic 25 minutes	WM preserved during anticipation of the stressor but poorer immediately afterwards.
Schoofs, Preuß & Wolf	2008	Participants completed the TSST before their WM performance was examined.	Working Memory	TSST PS / SE 20 minutes	Stress resulted in significant WM impairments, but this diminished the longer the task continued.
Schoofs, Wolf & Smeets	2009	Participants completed the CPT before their WM (requiring exec. function) was tested.	Working Memory	CPT Environmental 3 minutes	Stress significantly impaired multiple types of WM requiring exec. function.
Smeets, Jelicic & Merckelbach	2006	Participants completed the TSST before their memory was tested for emotion and neutral words.	Memory	TSST PS / SE 20 minutes	Recall for neutral words was impaired following stress.
Starcke, Wolf, Markowitsch & Brand	2008	Participants completed a modified TSST before examining their decision making (gambling) ability.	Decision Making	TSST PS / SE 20 minutes	Stress led to disadvantageous decision making, even with explicit guidance.
Tops, van der Pompe, Bass, Mulder, Den Boer, Meijman & Korf	2003	Participants administered 10 mg Cortisol before being tested for recall of emotional words.	Memory	Administered Cortisol Pharmacological n/a	Stress impaired recall of neutral and positive words, but not negative words.
Vedhara, Hyde, Gilchrist, Tytherleigh & Plummer	2000	Participants memory and attention was tested during periods of low stress and high stress (exam period).	Memory and Attention	Exam period Naturalistic Extended - Exam days	Short-term memory was enhanced during high stress period however attention was impaired and primacy effects reduced.
Weerda, Muehlhan, Wolf & Thiel	2010	Participants completed the TSST before their WM was examined.	Working Memory	TSST PS / SE 20 minutes	WM accuracy improved following stress.
Zandara, Garcia-Lluch, Pulopulos, Hidalgo, Villada & Salvador	2016	Participants completed the TSST before their WM was examined.	Working Memory	TSST PS / SE 20 minutes	Females attention and WM performance improved following stress, but not males.

* PS / SE = Public Speaking / Socially Evaluative stressor

1.4 The Effects of Acute Stress on Attention

The impact of stress on attention can be substantial and the importance of understanding these effects are reflected in the large volume of literature generated. Indeed, a search of an online database with the key terms "psychology", "attention", and "stress" returns in excess of 35,000 results ("EBSCOhost search", 2018).

1.4.1 What is Attention?

Attention is often described as "one of the most important cognitive functions" (Sänger, Bechtold, Schoofs, Blaszkewicz, & Wascher, 2014, p.1) and was initially defined by James (1890) as the ability that allows "people to perceive, conceive, distinguish, and remember better than they otherwise could". Titchener (as cited in Yantis & Jonides, 1984), later added that attention determines "what people are conscious of, as well as the clarity of their conscious experience". More recently, Katsuki and Constantinidis (2014) have described attention as the process by which a person selects the most relevant stimuli to the task at hand, whilst concurrently filtering out irrelevant information. In a complex world that is rich in sensory detail, the brain's capacity to process all available information is limited. Thus, attending to the most important features or aspects of stimuli allows us to efficiently navigate to our environment and achieve our goals.

1.4.1.1 Theories of Attention

Attention is thought to comprise of two processes: top-down and bottom-up processing. Top down, or endogenous attention, is directed by current goals and knowledge and it is produced internally. Bottom up, or exogenous attention, is guided by sensory stimulation provided by the stimulus due to obvious and distinctive (e.g. pop-out) features (Connor, Egeth, & Yantis, 2004; Corbetta & Shulman, 2002; Katsuki & Constantinidis, 2014). How these processes function individually and interact together has been extensively investigated, particularly with regard to visual search (Egeth & Yantis, 1997). An early theory of visual attention was offered by Treisman and Gelade (1980).

They proposed that when performing a bottom-up visual search, targets with features that differed significantly from non-targets (colour or orientation) were able to be processed more efficiently as they 'popped out' and could be processed in parallel without examining each available stimulus. Alternatively, search guided by top-down factors such as explicit cognitive aims (goals) or implicit priming, is more onerous, requiring each stimulus to be examined in the absence of distinct feature differences between target and non-target (Wolfe & Horowitz, 2004). Despite the fact these processes are commonly thought of as operating independently, successful navigation of everyday life necessitates that they interact with and influence each other (Awh, Belopolsky, & Theeuwes, 2012; Katsuki & Constantinidis, 2014).

Other researchers such as Desimone and Duncan (1995) have hypothesised that allocation of attention is biased by whatever stimulus inside the visual field provokes the strongest neural reaction, initiated by location, feature or saliency. Each item is processed using their bottom-up information (e.g. colour) prior to their integration into a so-called "salience map", which represents the relevant distinctiveness of each stimulus. Koch and Ullman (1985) also suggested a "winner-takes-all" mechanism that allocates attention to whichever stimuli has the strongest neural activation within this "salience map". However, in addition to the saliency of any stimuli, relevance to current goals is also important for drawing attention. This has led researchers to hypothesise a priority map for representing the priority for each stimulus, thus integrating both top-down and bottom up processes (Serences & Yantis, 2006). However, such a view has led some researchers to suggest that a mutually exclusive view between the two attentional process is erroneous (Awh et al., 2012).

Within the psychological stress literature, attention has proven to be a rich line of enquiry, demonstrating attentional improvements and decrements following exposure to both episodic acute stress and chronic stress (Doxie, 2014; McEwen, 2001). As an illustration, one report shows that air traffic controllers, regularly exposed to acute stress

throughout their careers, increase their levels of focus (selective attention), sustained attention and resistance to interference over time (Ribas et al., 2010). However, a larger share of the research has considered how attentional processes are affected when experiencing acute stress. Unsurprisingly, this area is similarly complex and inconsistent as to the nature of any improvements or impairments. (See Table 1.2 for a summary of these studies.)

1.4.2 Divided Attention

Divided attention is the ability to pay attention to, and successfully execute several tasks simultaneously. Perhaps more commonly thought of as multi-tasking it has been extensively linked to working memory, with Colflesh and Conway (2007) claiming that it is a key feature of successful divided attention.

One experiment by Matthews, Sparkes and Bygrave (1996) considered performance of non-professional drivers, who were each characterised on the basis of whether they found the experience of driving significantly stressful. The authors asked them to participate in a standard scenario-based, driving simulator task, whilst administering a concurrent cognitive-based task. In this particular study, the primary task of driving acted not only as one of the two tasks for divided attention, but also directly as the stressor. The results of the study indicated that upon the introduction of the secondary cognitive task, participants who experienced a high stress state whilst driving showed preserved performance in both cognitive function and execution of the driving task. On the other hand, low stress state drivers trended towards poorer performance in both the cognitive task and driving execution. Given that performance levels remained high despite participants engaging in multiple tasks, such preservation of driving performance whilst acutely stress actually represented a cognitive improvement, relative to controls. In this case, the authors concluded that the stress state induced by the dual-task paradigm led to efficiency improvements in attentional resource management and therefore preserved

cognitive function. Later work by Beste, Yildiz, Meissner and Wolf (2013) also found that when individuals had been subjected to an acute psychosocial stressor (Socially Evaluated Cold Pressor Task - SECPT), dual-task performance (both auditory and visual modes) was significantly improved. Once again, the authors concluded that cognitive improvements were borne from increased processing efficiency initiated by the additional task requirements.

These findings opposed earlier accounts provided by researchers such as Mayer and Treat (1977). In their study, Mayer and Treat reported that stressed drivers might be more susceptible to performance lapses when driving due to their inability to effectively manage their cognitive performance under stress. This could lead to a higher risk of being involved in an accident. Another study that demonstrated how stress negatively impacts divided attention was provided by Bohnen, Houx, Nicolson and Jolles (1990). They described how increased physiological change resulting from stress (Cortisol) manifested as poorer divided attention performance when participating in a four-hour, continuous cognitive test battery. More recently, divided attention performance in an auditory vigilance task was found to decrease as perceived levels of environmental stress increased (Petrac, Bedwell, Renk, Orem, & Sims, 2009). This pattern was further supported when Kaess and colleagues conducted an experiment examining whether acute stress, initiated using the "memory task under noise" paradigm, would affect dual-task performance (Kaess, Parzer, Koenig, Resch, & Brunner, 2016). The reported results demonstrate that dual task performance and consequently divided attention decreased in a linear fashion with the strength of reaction to the stressor.

There are however reports that stress exerts no influence on divided attention performance. One such example is provided by Tarazona, Cerón and Lamprea (2013) who examined divided attention in 38 students following a modified TSST. Their results showed that despite an increase in Cortisol production, indicative of a stressful experience, there was no change to performance in a divided attention task (the Paced Auditory Serial

Addition Task). However, this could have been as a result of insufficient power due to the relatively small sample size.

1.4.3 Sustained Attention (Vigilance)

Sustained attention is the ability to maintain concentration and vigilance levels for an extended period of time, and has garnered particular attention with regard to stress research. Early interest was likely stimulated from the similarities between stress and sleep deprivation, which has for years been studied for its negative influence on sustained attention, or vigilance (Johnsen, Laberg, Eid, & Hugdahl, 2002; Lim & Dinges, 2008; J. F. Mackworth, 1968). Doran, van Dongen and Dinges (2001) employed significant levels of sleep deprivation as a psychophysiological stressor and examined how this affected performance on the Psychomotor Vigilance Task (PVT). In this task, participants respond to infrequently occurring stimuli as quickly and as accurately as possible. The results showed that those who had been allocated to the 'stress' condition (i.e. were sleep deprived) demonstrated significantly poorer performance than non-stressed participants. This was confirmed by slower reaction times and a greater number of lapses (missed targets) and false alarms. The authors concluded that exposure to this particular type of stress led to an instability of overall cognitive state that degraded cognition.

The observations of Doran et al. (2001) are not unexpected given the well-reported "Vigilance Decrement" phenomenon, first described by N. H. Mackworth (1948), whereby sustained vigilant performance tends to deteriorate over time. Indeed, early investigations provided similar conclusions. Hancock conducted a series of literature reviews concerning studies that measured sustained attention under conditions of stress, the first of which was concentrated solely on thermal stress, or excessive heat (Hancock, 1986). Hancock reported that the effect of thermal stress was damaging towards maintaining levels of sustained attention. He also described several studies that used vibration and noisy environments as stressors and demonstrated that they were able to

cause similar performance deficiencies to sustained attention (Koelega & Brinkman, 1986; Wilkinson & Grey, 1974; both cited in Hancock & Warm, 2003).

More recent studies have used the Sustained Attention to Response Task (SART) as a measure of vigilance. This computer-based task is able to determine sustained attention performance by measuring the ability of the participant to suppress responses to unpredictable and infrequent stimuli whilst responding to fast, rhythmic stimuli. Scholz et al. (2009) employed the TSST and reported that SART performance was significantly poorer following exposure to such psychosocial stress. Similarly, a later study using an alternative psychosocial stressor, the SECPT, also observed that sustained attention was significantly compromised, resulting in lengthened response times, fewer correct responses and reduced inhibition (Alomari, Fernandez, Banks, Acosta, & Tartar, 2015).

Becker, Warm, Dember and Hancock (1995) used a 40-minute vigilance task to measure sustained auditory attention performance in response to acute stress, specifically aircraft jet engine noise (95 dBs using a Doppler effect). As predicted, the authors reported a deficit in vigilant attention. Although a follow up study in 2009, which used the identical stressor, reported that the increased noise actually resulted in improved sustained attentional performance when compared to quiet conditions (Helton, Matthews, & Warm, 2009). Importantly however, the 2009 study measured vigilance in a task lasting just 12 minutes (three blocks each lasting four minutes) and it is possible that any vigilance deficits would not be observable in such a short time period. An alternative explanation was offered by the authors, who suggested that intermittent noise over a short period of time resulted in increased arousal levels, thereby sustaining attention and delaying any vigilance decrement. This effect is commonly found in sustained attention tasks where performance normally deteriorates after 15 minutes (Teichner, 1974). Helton and colleagues (2009) are not alone in their assertion that acute stress can initiate a positive effect on sustained attention. A study by Shackman, Maxwell, McMenamin, Greischar and Davidson (2011) measured event-related potentials (ERPs) in participants who were

threatened with, and subsequently delivered, electric shocks. They discovered that following exposure to this acute stressor, the neurological components known to reflect sustained attention showed conflicting effects. The magnitude of the ERP related to improved selectivity of visual attention increased, however this was followed by a reduction of a second component associated with task-focused attention. Such findings provided evidence that exposure to stress can result in altered neural processing, affecting an individual's ability to allocate attention appropriately. In this particular case, exposure to acute stress resulted in a transfer to a more vigilant, threat-assessing mode as opposed to a controlled task-directed mode, thereby improving vigilant attention.

1.4.4 Selective Attention

Selective attention, or the process by which an individual reacts to the occurrence or presence of a particular stimulus amongst other non-salient stimuli, presents a similar narrative. One seminal study quoted extensively in the literature is the aforementioned review and experiments conducted by Chajut and Algom (2003). The researchers employed several variations of the Stroop paradigm in order to thoroughly assess selective attention. The results suggested that under a range of stressors, attention uniformly narrowed as subjects became much more effective at selecting target stimuli, regardless of multiple conditions and whether the attentional process was automatic (bottom up) or controlled (top down).

The notion that selective attention improves under stress has been further supported across other studies using a variety of tasks and stressors. Hommel, Fischer, Colzato, van den Wildenberg and Cellini (2012) determined that in the presence of an acute auditory stressor (fMRI noise at 70 dBs), individuals' cognitive control improved such that they were able to switch between tasks more successfully, demonstrating effective deployment of their selective attention. Ellenbogen, Schwartzman, Stewart and Walker (2002) used a competitive computer task as a stressor, whereby participants

competed against a confederate either successfully, or losing repeatedly. Participants who repeatedly lost exhibited typical stress markers such as lower mood, but also demonstrated more efficient reorienting of attention than non-stressed individuals. Another widely cited study by Vedhara et al. (2000) also reported that selective attention during a telephone number search task was improved whilst undergoing a period of exams compared to a non-exam period (although their assertion that an exam period acts as an acute stressor appears generous).

Bruyneel et al. (2013) artificially induced and examined both positive and negative moods when exploring attention. Positive mood was induced using music and recall of positive memories, whilst negative mood was induced by way of emotive film clips or interviews (similar to TSST). The researchers found that negative affect significantly improved alerting efficiency, an important aspect of selective attention. Likewise, van Steenbergen, Band and Hommel (2011) measured pupil dilation and attentional selectivity in a saccade task and likewise found that whilst both positive and negative pictorial stimuli resulted in arousal, only exposure to the negative pictures induced a change to affect state. This state change led to a narrowing of attention, demonstrating an efficiency improvement to selective attention. Finally, a study by Roelofs, Bakvis, Hermans, van Pelt and van Honk (2007) used the TSST and measured selective attention by administering a masked, emotional stroop task. The authors reported that high Cortisol responders, i.e. those participants with the strongest biological response to the stressor, exhibited improvements to their selective attention. This was demonstrated by speeded reaction times to negative stimuli, compared to the low Cortisol responders.

However, that finding was in contrast to other biologically based-experiments such as the longitudinal study conducted by Lupien et al. (1994). In this study, annual measures of Cortisol, the same biological marker used in Roelofs et al. (2007), were collected. Although the study focused on an elderly population, the results demonstrated a relationship between increasing Cortisol levels and compromised selective attention in a

visual search task. Furthermore, it also demonstrated that the effects are relatively constant with increasing age (although it is necessary to point out there were likely a number of confounds linked to participants advancing age). More recently, Vinski and Watter (2013) subjected participants to the TSST before taking measures of negative mood, after which participants completed the SART task. The stressed participants demonstrated lower levels of selective attention for a short period following the stress exposure, evidenced by a greater number of errors and greater variation in response times. Notably, these effects diminished quickly post-stressor which led the researchers to suggest that stress exposure caused negative mood, that in turn provoked a short period of mind-wandering and reduced attentional focus.

A further study that focused more specifically on stress effects was performed by Elling et al. (2011) who used the CPT to induce stress and reported an interesting finding. Participants were asked to complete several iterations of a tonal dichotic listening task interspersed with exposures to the CPT and a warm water control condition. Following the CPT, participants demonstrated increased levels of distractibility and poorer selective attention for a very short period of time (4-7-minutes' post-stressor). The authors noted that any experimental design that tested participants outside of this short window would have failed to find such an effect on selective attention, thus highlighting how important it is to consider effects immediately following exposure to stress. The findings also highlighted the importance of making an allowance for the physiological reactions that take place during and after stress exposure, which will be discussed at length in a later section.

Elling and colleagues provided further evidence for an adverse effect of stress on selective attention by exploring the magnetoencephalographic (MEG) correlates of visual attention (Elling et al., 2012), specifically the N1m waveform amplitude. Following acute psychosocial stress exposure (the TSST), MEG recordings revealed greater source strength for the N1m amplitude amongst stress participants compared to controls. The authors

argued this was indicative of a general increase in distractibility of exogenous attention, implying poorer selective attention. Another neuroscientific study by Sänger et al. (2014) utilised Electroencephalography (EEG) rather than MEG, to examine how electrophysiological changes might affect attention and found similar results. The study reported that participants in the stress condition (SECPT) displayed less neural activation (event-related potentials magnitudes) following a change to a stimulus. The authors inferred that acute stress negatively affects the ability to intentionally allocate attention (i.e. select items to attend) following stress exposure.

Braunstein-Bercovitz (2003) examined the effects of stress and perceptual load, operationalised by altering target discriminability, on selective attention using a negative priming task whereby a distractor in one trial becomes the target in the subsequent trial. Negative priming is regarded to be highly related to both memory and selective attention (for review see Frings, Schneider, & Fox, 2015). Stress was induced by requiring participants to calculate and apply a challenging (difficult to discern) mathematical rule to a short series of digits. Highly stressed individuals demonstrated a larger effect of negative priming. The author concluded that exposure to acute stress resulted in increased interference from task-irrelevant stimuli, therefore reflecting impaired selective attention. Sato, Takenaka and Kawahara (2012) followed up this work examining load and stress. Their results showed that stressed participants only demonstrated increased interference when perceptual load (number of distractors) was high, showing virtually no interference when load was low. Importantly, these transformations were the opposite to those seen in the control group who demonstrated interference under low perceptual load which disappeared under high perceptual load. The reported findings suggest that stress exposure during low perceptual load might lead to relatively improved selective attention but that this effect is reversed when exposed to high perceptual loads.

The examples demonstrate the conflicting nature of the stress literature. It is

Table 1.2 *A summary of studies that examined the effect of stress on attention.*

Authors	Year	Method	Type of Attention Examined	Stressor / Type / Duration	Results
Beste, Yildiz, Meissner & Wolf	2013	Participants completed SECPT before being tested in a dual task paradigm ('tone' and 'letter' tasks).	Divided Attention	SECPT PS / SE 3 minutes	Stress resulted in speeded RTs and better ability to modulate performance between tasks.
Bohnen, Houx, Nicolson & Holles	1990	Stress induced using continuous performance task, with Cortisol level measured to understand extent of stress.	Divided Attention	Continuous Performance Task Cog. Overload 4 hours	Higher Cortisol response resulted in poorer attentional performance on divided attention test.
Kaess, Parzer, Koenig, Resch & Brunner	2016	Participants completed the 'memory task under noise' before completing a bespoke dual task paradigm.	Divided Attention	Memory Task Under Noise Cog. Overload Unknown	Stressed participants performance on the dual-task decreased in a linear fashion with the strength of reaction to stress.
Matthews, Sparkes & Bygrave	1996	Participants completed a driving task alongside a secondary cognitive task.	Divided Attention	Driving Naturalistic 15 minutes	Participants stressed by driving maintained dual-task performance, whilst non-stressed participants cognitive scores were poorer.
Mayer & Treat	1977	Analysed characteristics of drivers involved in accidents.	Divided Attention	Driving accidents Naturalistic n/a	Participants with poorer ability to orient attention across tasks were more likely to experience a crash.
Petrac, Bedwell, Renk, Orem & Sims	2009	Participants reported levels of environmental stress before being tested dual task paradigm.	Divided Attention	Perceived recent stress Naturalistic n/a	Higher self-reported stress was linked to poorer performance in an auditory dual-task.

Ribas, Lima Martins, Amorim, de Melo Guerra… & de Castro	2010	Examined Air Traffic Controllers split by experience. Greater experience led to lower stress levels, with participants then compared and measured performance over a battery of tasks.	Divided Attention	Air traffic Control Naturalistic n/a	Participants with higher levels of experience also demonstrated fewer stress markers, whilst performance across various dual tasks improved relative to high stress participants.
Tarazona, Cerón & Lamprea	2013	Participants completed the TSST before completing a divided attention task.	Divided Attention	TSST PS / SE 20 minutes	Stress led to no observable changes in divided attention performance
Alomari, Fernandez, Banks, Acosta & Tartar	2015	Participants completed the SECPT before their Event Related Potentials (ERPs) were measured throughout an emotional processing task.	Sustained Attention	SECPT PS / SE 3 minutes	Stress led to longer RTs, poorer accuracy and also reduced inhibition.
Becker, Warm, Dember & Hancock	1995	Participants sustained auditory attention was tested throughout 95 dB noise or quiet.	Sustained Attention	Noise Environmental 40 minutes	Stress (noise) led to poorer vigilant attention and an inability to utilise feedback.
Doran, van Dongen & Dinges	2001	Participants were sleep deprived before completing the Psychomotor Vigilance Task (PVT).	Sustained Attention	Sleep loss Environmental 88 hours	Stressed participants exhibited slower RTs and significantly more lapses of attention (misses and false alarms).
Hancock	1986	Reviews a number of studies exploring attentional performance following heat stress.	Sustained Attention	Heat and cold Environmental Various	Multiple reports of exposure to excessive heat resulting in poorer sustained attention.
Hancock & Warm	2003	Reviews a number of studies exploring how vibration and noise affect attention.	Sustained Attention	Vibration / Noise Environmental Various	Multiple reports of vibration and noise negatively impacting sustained attention.
Helton, Matthews & Warm	2009	Participants sustained auditory attention was tested throughout intermittent 95 dB noise or quiet.	Sustained Attention	Noise Environmental 12 minutes	Stress resulted in improved sustained attention (possibly due to intermittent noise elevating arousal levels).
Johnsen, Laberg, Eid & Hugdahl	2002	Participants were sleep deprived before being tested in a dichotic listening task.	Sustained Attention	Sleep loss Environmental80 hours	Auditory selective attention was poorer following sleep deprivation (stress).

Lim & Dinges	2008	Reviews sleep deprivation studies where participants vigilance was tested using the PVT.	Sustained Attention	Sleep loss Environmental Various	Sleep deprivation leads to slower RTs, greater lapses, more errors of commission and enhances time-on-task effects.
Scholz, La Marca, Nater, Aberle, Ehlert, Hornung... & Kliegel	2009	Participants completed the TSST before being tested in a go/no-go task.	Sustained Attention	TSST PS / SE 20 minutes	Stress resulted in significantly impaired go/no-go task performance.
Shackman, Maxwell, McMenamin, Greischar & Davidson	2011	Participants were threatened with/delivered electric shocks whilst ERPs were measured.	Sustained Attention	Shock Environmental 20 minutes	During stress, activity in neural components associated with selective attention increased, representing a transfer to a more vigilant state.
Braunstein-Bercovitz	2003	Participants attempted difficult maths problems become completing a series of priming tasks at low and high perceptual loads.	Selective Attention	Arithmetic Cog. Overload 9 minutes	Stress resulted in larger negative priming effects as a result of increased interference (poorer selective attention).
Bruyneel, van Steenbergen, Hommel, Band, de Raedt & Koster	2013	Participants mood was affected (positive/negative) reflecting stress-like conditions before completing a visual attention task.	Selective Attention	TSST-like task PS / SE 15 minutes	Negative mood, closely related to stress resulted in improved alerting efficiency.
Elling, Schupp, Bayer, Bröckelmann, Steinberg, Dobel & Junghofer	2012	Participants completed a TSST-like stressor before testing visual attention (emotional and neutral pictures).	Selective Attention	TSST-like task PS / SE 10 minutes	Stress participants were more likely to demonstrate distractibility.
Elling, Steinberg, Bröckelmann, Dobel, Bölte & Junghofer	2011	Participants completed the CPT then completed multiple iterations of a tonal dichotic listening task.	Selective Attention	CPT Environmental 3 minutes	Stress resulted in greater distractibility in the first 4-7 minutes.
Hommel, Fischer, Colzato, van den Wildenberg & Cellini	2012	Participants subjected to noise stress (fMRI noise at 70 dBs) before measured on task switching and cognitive control.	Selective Attention	Noise Environmental 50 min	Stress resulted in more successful task switching indicating improved selective attention.

Lupien, Lecours, Lussier, Schwartz, Nair & Meaney	1994	Longitudinal study in elderly population exploring the link between Cortisol and visual selective attention.	Selective Attention	Cortisol measurement Pharmacological n/a	Higher levels of Cortisol shared a significant relationship to poorer selective attention.
Roelofs, Bakvis, Hermans, van Pelt & van Honk	2007	Participants completed the TSST before completed a masked emotional Stroop task (emotional faces).	Selective Attention	TSST PS / SE 20 minutes	High Cortisol responders showed improved selective attention, albeit with a negative bias.
Sänger, Bechtold, Schoofs, Blaszkewicz & Wascher	2014	Participants completed the SECPT before completing a luminance change detection task.	Selective Attention	SECPT PS / SE 3 minutes	Stress led to higher error rates, particularly in top-down tasks, plus lower neural activation in areas associated with selective attention.
Sato, Takenaka & Kawahara	2012	Participants completed TSST-like speech exercise before completing a visual attention (flanker task) at different levels of load.	Selective Attention	TSST-like task PS / SE 10 minutes	Stress led to increased interference only when perceptual load level was high, but not when load was low.
van Steenbergen, Band & Hommel	2011	Participants completed a saccade task with pupil dilation used to measure reactivity to threat (stress).	Selective Attention	Emotional pictures Aversive Stimuli 8 minutes	Viewing negative pictures resulted in an affective change which then resulted in improved selective attention.
Vinski & Watter	2013	Participants completed the TSST before completing the Sustained Attention to Response Task (SART).	Selective Attention	TSST PS / SE 20 minutes	Stress led to more errors and greater variability in RTs (poorer selective attention) temporarily.

* Chajut & Algom (2003) and Vedhara, Hyde, Gilchrist, Tytherleigh & Plummer (2000) were summarised in Table 1.1

important to note in any review of stress research that the manifestations of stress are not simply good nor bad, but can alter depending on a large number of changeable factors, or an interaction thereof (Hancock & Warm, 2003).

1.5 Discrepancies

The preceding section describes research that has been carried out in an attempt to understand the psychological and behavioural effects that stress can induce. However, there is little consensus whether these effects are positive or negative. Nor is it clear whether they affect all cognition, focus on particular aspects such as attention, or are more specific still and only impact their sub-processes such as selective attention. Further, it is unknown whether effects are stable across different situations and therefore form evidence for a holistic theory of stress or change depending on the environment or situation (for review see Staal, 2004).

There are several reasons why the stress response could have manifested in these different ways throughout the literature, with one likely explanation the differences between the individuals examined in samples of different studies. For instance, Beilock and DeCaro (2007) found that individuals with higher working capacity were more likely to exhibit effective problem-solving strategies under stressful conditions. Another examined stressed performance of air traffic controllers and found that individuals with greater levels of experience of a specific task demonstrated less susceptibility to stress and actually improved performance relative to less experienced individuals (Ribas et al., 2010). These effects could be particularly important in those studies that attempt to employ more representative or naturalistic tasks, such as serial number or telephone number search tasks, as opposed to abstract laboratory tasks (e.g. stroop tasks).

Others have found that personality type can affect individuals' responses to stress. Gunthert, Cohen and Armeli (1999) reported that individuals who rated as highly neurotic were less able to deploy successful coping strategies in response to stressful situations;

whilst work by Westman (1990) has shown that individuals who exhibited higher levels of hardiness were protected from the negative effects of stress on performance. In addition, individuals who experience high levels of support from their peers or co-workers are less likely to see stress-related performance deficits (AbuAlRub, 2004). Other individual factors such as locus of control and coping style (linked to appraisal) are also likely to play a part (for review see Leblanc, 2009).

Coping is particularly important given its position of influence in recent transactional models of stress. A study by Saxby, Matthews, Warm, Hitchcock and Neubauer (2013) examined how coping affected participants in a driving simulator task. Two types of fatigue were induced in drivers; passive fatigue resulting from monotony and boredom (low stress), and active fatigue resulting from cognitive overload (high stress). The results demonstrated that high stress, characterised by overloading cognitive capabilities, led to heightened coping efforts and perceived greater workload. However, exposure to lower stress led participants to appraise the situation as less challenging, which in turn reduced their task engagement and led to reduced alertness. The results demonstrate that exposure to even low amounts of stress can have a harmful impact if the stressor is not adequately appraised nor appropriate resources applied. Other studies have found that populations who tend to exhibit poorer coping strategy selection, such as schizophrenics, also exhibit higher levels of stress-related symptoms (Horan et al., 2007).

1.5.1 The Attentional Networks

Another possible cause of the conflicting findings across the literature is related to experimental designs, particularly with regard to attention, where different sub-domains of attention are commonly examined with varied designs and countless tasks (see section 1.4). One possible way to mitigate these effects would be to examine attention in a different way, perhaps considering defined attentional efficiencies. A popular theory of attention posited by Posner and Petersen (1990) (subsequently updated in Petersen &

Posner, 2012) is the attentional network framework. The authors describe the brain's attention system as consisting of three anatomically distinct networks responsible for controlling the attentional processes of *Alerting* – i.e. reacting to stimuli; *Orienting* – i.e. attending to signals in a known area (or switching between tasks); and *Executive Control* – i.e. selecting salient stimuli amongst distractors (or conflict resolution or decision making).

Many studies have examined these networks and, despite their originally hypothesised functional and anatomical independence, the three networks often show high levels of interaction during attentional task performance (Callejas, Lupiáñez, Funes, & Tudela, 2005; Fan et al., 2009; Hussain & Wood, 2009). Such interaction could be an influential factor for some of the inconsistencies witnessed within the stress-attention research. Conventional attention tasks, such as the Stroop Task, while focusing on a process such as selective attention, also engage multiple networks defined by Posner and Petersen. For instance, within the Stroop Task both alerting (reacting to the stimulus), and executive control networks (inhibiting the incorrect response) are engaged. Alternatively other selective attention tasks, including filtering tasks like that used by Palmer and Moore (2009) not only require irrelevant stimuli to be ignored but also require attention to be directed towards cued targets, thus engaging the orienting network. Therefore, it is entirely possible that the differences reported for a particular attentional process are driven by stress exposure affecting different or additional networks engaged in a particular task.

1.5.2 Inducing Stress

A final explanation for the inconsistency in the literature concerns the range and breadth of stressors employed across the research area. The variety of stressors is considerable and potentially problematic, with many stressors lacking ecological validity or representativeness towards real life situations. Even findings from studies employing naturalistic stressors such as fire-fighting exercises (Robinson et al., 2013), exam periods (Hoorelbeke et al., 2015) or natural disasters such as earthquakes (Kemp, Helton,

Richardson, Blampied, & Grimshaw, 2011) are likely constrained to those specific, yet exceptional circumstances.

Additionally, other more established lab stressors were often designed with particular definitions of stress in mind. As an example, a popular stressor such as the CPT has been shown to evoke a measurable behavioural, psychological and physiological stress response (Duncko et al., 2009; Ishizuka et al., 2007; Schoofs et al., 2009). However, whilst this stressor satisfies the criteria set forth by Smith and Vale (2006); that is to say a stressor should demonstrate a real or perceived threat to homeostasis, the CPT does not present any sort of socially-evaluative threat to the participant's ego, as mandated by Lazarus and Folkman's definition (1984). According to Lazarus and Folkman, the lack of any social evaluation will mean a less potent reaction than the Socially Evaluated Cold Pressor Task (SECPT). In this version, participants are told they are being filmed during the task with their reactions being compared against their peers, provoking a social threat. Support for this particular point is offered by Dickerson and Kemeny (2004) who performed an extensive meta-analysis and found that physiological responses (elevation of Cortisol levels) are strengthened when stressors contained a socially-evaluative threat compared to without. This finding was further reinforced by Schwabe, Haddad and Schachinger (2008) when they compared the physiological reactivity of participants following exposures to either the Cold Pressor Task or the Socially Evaluated Cold Pressor Task. Participants who encountered the socially evaluative component exhibited stronger physiological reactions to the stressor, generating greater levels of Cortisol. Whilst this study did not compare performance on any cognitive tasks, the implication is that a stronger physiological reaction is invoked due to higher levels of stress which may subsequently impair cognition to a greater extent. These studies highlight the importance of choosing the most appropriate method for inducing stress during an experiment.

1.5.2.1 Types of Stressor

Hermans, Henckens, Joëls and Fernández (2014) defined a stressor as a physical or psychological event that threatens an organism's homeostasis. Many stressors have been employed by researchers over the years, however, they can generally be categorized as one of the following: 1) cognitive stressors (including those that induce overload), 2) environmental stressors, 3) aversive stimuli, 4) naturalistic or experiential stressors, 5) pharmacological stressors, and 6) public speaking / socially evaluative stressors.

1.5.2.1.1 Cognitive Stressors

Cognitive-style stressors require participants to complete mental tasks; often these are difficult, or even impossible to complete successfully, or else they include multiple components/tasks that cause the participant to become cognitively overloaded and subsequently overwhelmed. Popular examples of this type of stressor include mental arithmetic tasks (Giles, Mahoney, Brunyé, Taylor, & Kanarek, 2014; Qi, Gao, Guan, Liu, & Yang, 2016), number series tasks and continuous performance tasks (Bohnen et al., 1990; Chajut & Algom, 2003; Stroop, 1935). Another, more modern exemplar of a cognitive stressor, is the multi-tasking framework developed by Wetherell and Sidgreaves (2005 - originally called the Defined Intensity Stressor Simulation). In this task, participants are required to complete as many as four individual tasks, concurrently. Further, the difficulty of each task can be manipulated enabling the tool to dynamically induce different levels of stress depending on the requirements of the researcher. One benefit of this is that the task can act both as the stressor, and as a measure of performance, as participants are scored on each element of the framework (also true of some experiments employing the Stroop or continuous performance tasks). However, when these tasks are used in addition to a different task measuring cognitive performance, there is the potential for performance to be confounded as a result of cognitive fatigue. Occasionally, as an addition to these tasks, some researchers will try to increase the level

of stress with the introduction of time constraints or even "false feedback". In these "false feedback" paradigms, participants are given instructions on how to complete the task successfully and then are provided with predetermined, negative feedback explaining that they are performing poorly, or below the stated requirements. This negative feedback pressures the participant and increases their levels of stress (Delawalla, 2010; Hoorelbeke et al., 2015).

Cognitive stressors benefit from their flexibility and the manner in which they are operationalised. For instance, it is relatively easy to induce stress quickly using a stroop task or a mental arithmetic task (Chajut & Algom, 2003), although longer duration versions of the tasks can also result in similar levels of stress (Qi et al., 2016). Taking the multitasking framework as an example, although many studies have asked participants to perform the task for at least 20 minutes to induce stress (Roberts, Wetherell, Fisk, & Montgomery, 2015; Scholey et al., 2009), others have successfully demonstrated increases to perceived levels of stress and workload in as little as five minutes (Wetherell & Sidgreaves, 2005). Additionally, owing to the dynamic nature (multitasking framework and mental arithmetic tasks) or the instinctive manner of the task (Stroop), stressors of this type can often be performed multiple times by participants without losing any of their effectiveness (Provost & Woodward, 1991).

The ability to quickly induce stress is important as cognitive performance following exposure is likely to be influenced both by the proximity to the stressor, and the different physiological reactions initiated by stress exposure (see 1.5.3 – Time Course and Physiological Responses to Stress). However, some cognitive stressor tasks lack important elements for stress induction, such as the requirement for tasks to feel uncontrollable (Koolhaas et al., 2011), or threat of being socially evaluated (Lazarus & Folkman, 1984) e.g. the mental arithmetic or stroop tasks. Further, previous work has shown that these tasks do not always elicit some of the physiological responses associated with, and commonly measured in stress research. As an illustration, although completing the

multitasking framework has been shown to impact on immune functioning associated with acute stress exposure (specifically secretory immunoglobulin-A – Wetherell & Sidgreaves, 2005), the task is reported not to induce any increased activation of the HPA-Axis, as demonstrated by increased production of the stress hormone Cortisol (Wetherell, Craw, Smith, & Smith, 2017). Similarly, a recent adaptation of the Stroop task was shown to increase SNS activity, by way of altered heart rate variability (Vanitha, Suresh, Chandrasekar, & Punita, 2017), however there is little evidence that performing stroop tasks increases HPA-Axis activity (Dupuis, 2018).

1.5.2.1.2 Environmental Stressors

Environmental stressors have been used across stress research for decades and generally introduce a notable change to the participants environment when completing a task. Examples have included excessive heat (Ramsey, 1995; Sun et al., 2012) or cold (Hancock, 1986; Morris & Pilcher, 2016; see also Gailliot, 2014), noise (Becker et al., 1995; Helton et al., 2009; Kaess et al., 2016), as well as mental fatigue or sleep loss (Marcora, Staiano, & Manning, 2009; Stokes & Kite, 1994). Additionally, time pressures (Matthews & Campbell, 1998, 2009) or presenting a threat to participants, such as angry faces (Roelofs et al., 2007), images of gunmen (Akinola & Mendes, 2012), or the possibility of receiving a shock (Hansen, Johnsen, & Thayer, 2009) have also been employed to induce stress. The adverse conditions introduced by stressors such as temperature and noise disturb the bodies homeostatic state and increase levels of anxiety and/or arousal (Hancock, 1986), whilst fatigue-based stressors and time pressures rely on the participant feeling overloaded or overwhelmed leading them to poorly appraise either the task, or their capability to successfully complete the task (Matthews et al., 1996). Perhaps the best-known example of an environmental stressor is the Cold Pressor Task, first introduced in 1936 (Hines & Brown, 1936). In this task, participants are asked to immerse a body part, usually their hand, elbow or foot, in cold water (~3 degrees) for a

period of up to three minutes. The initial shock of the cold temperature initiates an immediate autonomic response, and the task has been shown to reliably induce HPA-Axis activity (Schoofs et al., 2009; Skoluda et al., 2015).

However, other environmental stressors are often introduced concurrently as the participant completes a cognitive task. This offers researchers a distinct advantage as it allows them to clearly separate stressed and non-stressed performance by measuring participants in both the presence and absence of a stressor (Sun et al., 2012). Further, by analysing performance in epochs throughout exposure, it would be possible to understand how performance evolves following the introduction of the stressor (Hancock, 1986). However, other types of environmental stressor – such as threatening images – are presented to participants prior to performance in order to place participants in a stressed state. This means that environmental stressors offer a good deal of flexibility to researchers depending on their experimental requirements. Additionally, some stressors of this type have been shown to elicit physiological responses (e.g. threat of shock - Berghorst, Bogdan, Frank, & Pizzagalli, 2013; CPT - Schoofs et al., 2009; heat - Vangelova, Deyanov, Velkova, Ivanova, & Stanchev, 2002). However, this is not always the case (thermal stress - for review see Hancock, 1986). Moreover, whilst concurrent stressors are advantaged by being able to manipulate the duration of exposure (depending on the length of task), pre-presented environmental stressors (with the exception of the CPT), such as threatening images (i.e. of gunmen / angry faces) require longer periods of exposure to induce sufficient feelings of stress (Richards, Hadwin, Benson, Wenger, & Donnelly, 2011). This could provide a potential confound for experiments wishing to explore the time-course of stressed performance. Further, whilst participating in a stressful task (e.g. the CPT) may cause participants to appraise the experience as unpredictable or uncontrollable and therefore stressful, being presented with affective images is less likely to be appraised in such a manner.

1.5.2.1.3 Aversive Stimuli

Aversive stimuli stressors share some similarities with the aforementioned threat stressors and are normally introduced as affective films (Renner & Beversdorf, 2010), vignettes (Johnson et al., 2014), or video games (Akinola & Mendes, 2012; Skosnik, Chatterton, Swisher, & Park, 2000). Others have used affective images (Richards, Benson, Donnelly, & Hadwin, 2014) or employed an emotional version of the Stroop task that incorporates images of emotional/expressive faces (Dandeneau et al., 2007; Roelofs et al., 2007). Aversive stressors work by initiating an affective state change in participants that alters mood, as well as increases anxiety and arousal levels (Grillon et al., 2009). Further, they been shown to impact on physiological biomarkers of stress such as cortisol (Dandeneau et al., 2007). However, stressors of this type must be introduced prior to the measured task and often require prolonged periods of administration (e.g. 30 minutes) to be sure a sufficient experience of stress has been initiated (Renner & Beversdorf, 2010). Unfortunately, this means that at the point participants commence a task where performance is being measured, they are likely to be past the immediate stages of stress associated with increased SNS activity, and instead may already be experiencing increased HPA-Axis activity where the body is attempting to recover from the stress and return to a homeostatic state (Herman & Cullinan, 1997; Skosnik et al., 2000). Therefore, aversive stressors should be avoided in studies examining how performance is altered in the immediate aftermath of stress (e.g. when SNS activity is increased).

1.5.2.1.4 Naturalistic / Experiential Stressors

Naturalistic or experiential stressors have also been used extensively throughout the literature exploring performance changes following acute stress. Examples include common daily stressors (Bolger et al., 1989; Neupert et al., 2006) and driving simulation tasks (Desmond & Matthews, 1997; Matthews et al., 1996), as well as less common experiences, such as fire-fighting (Robinson et al., 2013), skydiving (Bourne Jr & Yaroush,

2003; Leach & Griffith, 2008; Schommer, Hellhammer, & Kirschbaum, 2003) and Helicopter Underwater Evacuation Training (HUET – Robinson et al., 2008). The advantage of such stressors is that they can be performed in naturalistic settings outside of a laboratory, and therefore offer a much more representative insight into an individual's experience of stress. This is particularly true when measuring daily stressors, which is often collected using ambulatory measures of physiology, coupled with diary entries that identify when/what stress was experienced and how it affected them (King, Oka, & Young, 1994; Vrijkotte, van Doornen, & de Geus, 2000), or, in the case of driving tasks, through the use of highly realistic simulators (Matthews, 2001; Matthews et al., 1996). Even uncommon stressors, such as skydiving and performing the HUET benefit from naturalistic environments (as opposed to the laboratory) and are understood to initiate realistic examples of stress, as opposed to the artificial experiences of some laboratory stressors (e.g. the CPT) (Robinson et al., 2008).

Others have attempted to bring more realistic experiential stressors into the laboratory, as is the case with the bicycle ergometer task (Allgrove et al., 2008; Skoluda et al., 2015). In this instance, participants are tasked with effortful cycling in order to increase physical exertion, which has been shown to reliably induce both autonomic and HPA-Axis responses related to stress. As the majority of people will have experienced cycling, the task offers greater ecological validity than other novel tasks, such as the CPT; however, this means that it is less likely to be viewed as unpredictable or uncontrollable and therefore participants might not report themselves as being stressed (Koolhaas et al., 2011). Other researchers have measured performance during periods of examination, in order to capture realistic stress levels (Vedhara et al., 2000). However, whilst stress levels are undoubtedly likely to be elevated, it is difficult to justify this methodology as capturing acute stress (Vedhara et al., 2000).

Some of the most naturalistic studies have employed as their stressors natural disasters (Helton, Head, & Kemp, 2011; Horan et al., 2007), acts of terrorism (Holman et

al., 2008), or even combat stress (Lieberman et al., 2005; Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002). These studies benefit from capturing performance following genuine experiences of stress and much greater examples of physiological activity. However, they are often the most problematic logistically, present difficulties collecting reliable data in the immediate aftermath of stress and are likely to be confounded by multiple other factors, such as bereavement and fatigue (Holman et al., 2008; Lieberman et al., 2005). Even tasks such as fire-fighting and performing the HUET, whilst offering excellent data with regard to self-report and physiological measures, are often limited as they usually consist of training examples. Further, performance measures are usually collected at the end of sessions and therefore are usually outside of the more immediate SNS period of stress activity (Robinson et al., 2013, 2008).

1.5.2.1.5 Pharmacological Stressors

Pharmacological studies operate by artificially manipulating physiological pathways associated with stress exposure, such as administering (Newcomer et al., 1999) or artificially reducing levels of cortisol (Lupien et al., 2002). Often, such studies are the best controlled – certainly for measuring physiological influences of cognitive performance – owing to the higher level of control researchers have over the participants' physiology. However, there are inherent issues which such designs. Primarily, as the participant is not required to undertake any stressful task, there is a distinct lack of any self-reported stress, or appraisal, an important component of experiencing stress (Koolhaas et al., 2011; Lazarus, 1966, 1993; Staal, 2004). Further, Robinson and colleagues (2008) showed that physiological responses do not always match psychological experiences of stress. Therefore, any studies that neglect to include a task that could impact a participant's psychological state are likely to miss out on a large component of what influences stressed performance.

1.5.2.1.6 Public speaking / Socially Evaluative Stressors

The final type of stressor is related to social evaluation and examples often employ some aspect of judgement on the participants' performance to induce psychological stress. Historic examples generally focused on public speaking tasks (for review see Dickerson & Kemeny, 2004), however more recently researchers have added cognitive or physical components to increase anxiety and/or arousal (Schwabe et al., 2008).

The most popular of these is perhaps the most commonly used stressor across the stress literature, the Trier Social Stress Test (TSST - Kirschbaum et al., 1993). In this protocol (and its variants) participants are usually tasked with quickly learning a novel subject in order to deliver a short presentation, as well as complete a difficult mental arithmetic task, in front of a judgemental panel. The protocol is unpredictable, is viewed as uncontrollable by the participant and it creates an element of cognitive overload, thus participants appraise it as stressful. Further, having to perform the tasks in front of a panel (that is often trained to remain impassive or even appear discouraging) introduces a psychosocial threat (Kirschbaum et al., 1993), an important factor when inducing stress (McGrath, 1976). The TSST remains popular as, in addition to the cognitive load and social evaluation resulting in self-reported feelings of stress, it is also able to elicit key physiological responses (SNS and HPA-Axis activity – Skoluda et al., 2015). Further, these are normally stronger than those experienced for other tasks such as the CPT and the bicycle ergometer task (Skoluda et al., 2015). However, as the task can often take up to 20 minutes to administer it is difficult to measure cognitive performance in the SNS activity period, despite eliciting an SNS response.

More recently, Schwabe and colleagues (2008) developed a socially evaluative version of the CPT (SECPT) where, in addition to immersing a body part in cold water, participants are deceived into believing their experience is being recorded in order to compare performance against other participants, thus introducing a socially evaluative threat. Although the protocol lacks any genuine cognitive component, the addition of a

socially evaluative threat makes it somewhat comparable to the TSST, and a more intense stressor than the original CPT - able to elicit stronger physiological responses (Schwabe et al., 2008). Although these may not be as intense as the TSST (Skoluda et al., 2015), the rapid administration of the task (~ 3 minutes) gives the SECPT one distinct advantage over the TSST, meaning that researchers wishing to explore how stressed performance evolves, can do so almost immediately after the stress responses commence.

Inevitably, different stressors in diverse environments will invoke different strengths of reactions and therefore, unsurprisingly, studies using dissimilar stressors will lack consistency in their explanation of the effects on cognition. However, this observation leads to another fundamental factor that has been explored extensively in the literature, but which seemingly has been overlooked as a potential cause for the inconsistencies – the influence of a participant's biology and their physiological reaction.

1.5.3 Time-course and Physiological Responses to Stress

It is well understood that when exposed to acute stress, an individual's reaction will include both behavioural and psychological changes. Crucially, the reaction will also result in physiological changes and these can heavily influence the former (Bourne Jr & Yaroush, 2003). At the point of stress exposure, two of the physiological pathways within the endocrine system are activated "to form the basis for adaptation and survival in the face of adversity, threat, and challenge" (Compas, 2006, p.227). One responsibility of the endocrine system is to temporarily increase energy levels in preparation to encounter a threat, before returning to homeostatic control and baseline levels of activity (Frodl & O'Keane, 2013). However, this increase is often at the expense of processes that are deemed to be non-essential, such as regulation of the immune system (Sapolsky, 1992 as cited in Robinson et al., 2008).

1.5.3.1 Stress Physiology

Herman and Cullinan (1997) described these two pathways: the first originates from the Sympathomedullary (SAM) system and engages the Sympathetic Nervous System (SNS). The SNS releases the catecholamines 'adrenaline' and 'noradrenaline', produced in the adrenal medulla and this activation is considered the rapid response to stress exposure. It is characterised by changes such as increased heart rate, blood pressure and respiration, sweating palms and a significant decrease in digestive activity. This response is commonly conceptualised as the 'fight or flight' response to stress. The pathway is active from the moment of stress exposure and peaks within the first 10-15 minutes before quickly retreating to normal, pre-stressed levels. The second pathway is part of the Hypothalamic-Pituitary-Adrenal (HPA) Axis. Although the HPA-Axis activates immediately following exposure (similar to the SNS), it proceeds more gradually due to its "cascading" response and peaks approximately 25-45 minutes after onset. Corticotrophin-releasing hormone (CRH) is secreted within the hypothalamus, which leads to the production and release of adrenocorticotropic hormone (ACTH). ACTH is able to pass into the individual's bloodstream and trigger the release of glucocorticoids produced within the adrenal cortex, such as Cortisol in humans. However, the HPA-Axis manifests with fewer perceptible bodily changes (such as the heart rate and blood pressure increase observed with the SNS). Therefore, an individual may subjectively feel or appear as though they have recovered from the stress exposure, despite this ongoing physiological response. However, many studies report that cognitive faculties are still severely affected whilst this pathway is actively engaged.

Compas explains that both pathways "are innervated by the amygdala and the hippocampus, and are partially modulated by activity in the regions of the prefrontal cortex (PFC)" (Compas, 2006, p.228). This offers an explanation for why the physiological response can significantly influence cognitive processes such as attention which is also borne from the PFC (Rossi, Pessoa, Desimone, & Ungerleider, 2009).

Clearly the neurophysiological response to stress is well understood, and there are commonalities between the neuroanatomy of executive functions such as attention and the activated stress response. Despite this, little effort has been made to explicitly measure cognitive change during time periods aligned with the physiological response to stress. Whilst some studies have indeed examined cognitive change during the immediate aftermath of stress (Elling et al., 2011), others have measured following a short delay (between 5 and 60 minutes - Plessow et al., 2011; Sänger et al., 2014). Others still have considered the effects of acute stress as much as 24 hours later (Bolger et al., 1989). Realistically, whether down to the stressor itself, the individual's appraisal and ability to cope, or their underlying physiology, it is probable that the impact of stress on attention is moderated by time from exposure. As such, measurement of attentional change during different periods post-stress is likely to elicit different results. However it appears very few studies have attempted to measure multiple periods (some examples that have include Alomari, Fernandez, Banks, Acosta, & Tartar, 2015; Robinson, Leach, Owen-Lynch, & Sünram-Lea, 2013).

1.5.3.2 Stress Biomarkers

Observing the physical manifestations of the SNS reaction initially led researchers to use a variety of methods to capture the stress response. These included skin conductance, blood pressure and heart rate variability in an attempt to match stress induced physiological reactivity to cognitive changes (Andersson & Finset, 1998; King et al., 1994; Task Force of the European Society of Cardiology and the North American Society of Pacing and Elecrtophysiology, 1996). For instance, Patton (1970) examined the autonomic (SNS) effects of concurrently applied stressors on adult males enlisted in the United States Army. Patton found that both individual stressors, and multiple stressors were able to independently produce an increase in SNS activity when measuring pulse rate, systolic and diastolic blood pressure, skin conductance and palmar resistance. More recently, Vrijkotte,

van Doornen and de Geus (2000) investigated how ambulatory heart rate, blood pressure and heart rate variability was affected by stress in the workplace. However, despite these elements often demonstrating changeability in the face of stressors, and evident relationships with coping factors such as resilience (Hansen et al., 2009), these measures have not always been associated with discernible cognitive improvements or impairments (Stawski, Sliwinski, & Smyth, 2009).

Perhaps it is for this reason more contemporary studies have instead turned to the measurement of the salivary protein enzyme Alpha Amylase (collected from saliva hence salivary Alpha Amylase, or sAA). sAA has taken a principal position in stress research following its validation as a reliable indicator of SNS activity (Nater & Rohleder, 2009; Rohleder, Nater, Wolf, Ehlert, & Kirschbaum, 2004). As an example, Skoluda et al. (2015) examined sAA responses to various laboratory stressors that differed in intensity. They found that sAA levels demonstrably increased following each exposure, in line with subjective measurements and the intensity of the stressor. Other studies have directly attempted to link these increases with cognitive changes such as impaired cognitive flexibility or working memory (Plessow et al., 2011; Schoofs et al., 2008).

The introduction of sAA collection as a method for SNS measurement was likely influenced by the long standing practice of collecting salivary Cortisol as a reliable measurement of HPA-Axis activity (for review see Kirschbaum & Hellhammer, 1994). Many studies have employed Cortisol measurement in their attempt to understand whether stress affects various aspects of cognition such as memory and recall (Glienke & Piefke, 2016; Jelicic et al., 2004), mood (Het, Schoofs, Rohleder, & Wolf, 2012), working memory (Schoofs et al., 2009; Zandara et al., 2016), decision-making (Putman, Antypa, Crysovergi, & van der Does, 2010) and attention (Vedhara et al., 2000). Further, Cortisol levels have been manipulated with the use of laboratory-based stressors (Roelofs et al., 2007; van Stegeren et al., 2008), naturalistic stressors (Robinson et al., 2008; Vedhara et

al., 2000) and pharmacological intervention (Henckens, van Wingen, Joëls, & Fernández, 2012).

Thanks to the endeavour of such research, it is now well understood that not only are the processes of each pathway different (such as the amount of time they are each active), but so too are their reactions to the particular stressor they are exposed to. For instance, some stress researchers posit that the HPA-Axis responds with greater levels of activation, persists for a longer period of time, and that its return to homeostasis following exposure is much more gradual than the SNS response (Schommer et al., 2003).

Additionally, there is also evidence that responses can be modulated by experience or pre-exposure to the stressor but that this effect is limited to the HPA Axis (Grissom & Bhatnagar, 2009). An example is provided by Gerra, Zaimovic, Mascetti and Gardini (2001) who twice subjected participants to a psychosocial stressor comprised of a public speaking task, a stroop colour word interference task, and a mental arithmetic exercise in front of an audience, one week apart. Whilst measures taken for the SNS (noradrenaline and adrenaline) showed similar reactivity following the second stress exposure, HPA-Axis measures (ACTH and Cortisol) showed significantly less activation than when first exposed to the stressor. This pattern not only highlights the adaptive ability of the HPA-Axis pathway, but suggests that repeated exposure to a similar or identical stressor is likely to manifest differently on aspects of cognition due to the physiological reaction of the individual being significantly different. These findings were further supported by Schommer et al. (2003) who also examined repeated exposure to the TSST. Schommer and colleagues measured 3 exposures across a period of 4 weeks, and reported similar findings to Gerra et al. (2001) in that HPA-Axis response was blunted in later exposures, whilst SNS reactivity remained stable. This work identifies the important effect experience can have as it appears the physiological response to a stressor can be habituated for a significant period following exposure, leaving a lasting impression on the individual and their physiological responses.

Interestingly, although the processes are distinct, there is some evidence that the HPA-Axis has an additive effect upon the SNS reaction. Elzinga and Roelofs (2005) measured Cortisol-induced impairments to working memory, and their interaction with the SNS reaction. The authors subjected each participant to the TSST, taking measures of both the SNS and HPA-Axis, before separating participants into Cortisol "responders" and "non-responders". The results showed that Cortisol responders demonstrated working memory impairments when both the SNS and the HPA-Axis were activated during the psychosocial stress phase. However, during the subsequent recovery phase, when the SNS activity had normalised but Cortisol levels were still elevated, the working memory performance of the Cortisol responder group did not differ from the non-responder group. Elzinga and Roelofs concluded that on some occasions, for instance when measuring working memory changes, both SNS and HPA-Axis activation are required in order for negative effects to manifest.

Despite this assertion, many studies when taking explicit measures of the physiological reaction have limited their scope to one of the two pathways, or only allude to the responsibility of one pathway. For instance, Elling et al. (2011) studied the effect of stress exclusively on the SNS pathway, stating this was for the explicit purpose of fulfilling a gap in the literature left by earlier studies focusing solely on the adrenocortical (HPA-Axis) response. Indeed, their finding that acute exposure to stress resulted in alterations to auditory selective attention would likely have been missed in studies lacking an SNS measurement, or that failed to test selective attention so soon after exposure. Another study by Weymar, Schwabe, Löw and Hamm (2012) performed the SECPT on participants before asking them to rate a series of unpleasant and neutral pictures according to their emotional valence. The authors took SNS measurements by way of heart rate and blood pressure and noted increases of each when compared to the control participants. However, as the picture coding exercise itself only commenced 20 minutes after exposure, outside of the known SNS reaction period, participants SNS would likely have returned to baseline

levels. Therefore, these measures were only useful to validate that stress had been successfully induced, rather than allow any conclusions to be made regarding the physiological response. Subsequent decrements probably related to ongoing HPA-Axis reactivity rather than as a legacy of earlier autonomic changes. Despite knowledge of this timescale, the authors drew no conclusion between the cognitive changes and the HPA-Axis response.

A 2010 study by Renner and Beversdorf investigated stress and cognitive flexibility, however the experimental design itself left any conclusion regarding the effect of the HPA-Axis unattainable (Renner & Beversdorf, 2010). The article reported that exposure to an unpleasant 30-minute film clip resulted in impaired cognitive flexibility. No such impairment was observed when participants were exposed to a neutral 30-minute film clip. However, each of the cognitive measures were completed within ten minutes of the stress exposure, therefore ignoring any potential changes that might occur to cognitive flexibility following SNS de-escalation and peak HPA-Axis activity. Highlighting this point, Plessow et al. (2011) examined cognitively flexibility following exposure to the TSST and found that compromised cognitive flexibility increased with time lag to stress exposure. In fact, the reported findings suggested no effect of the SNS (no change related to sAA) and that the cognitive flexibility decrement was linked to Cortisol levels (HPA-Axis marker). The changes reported by Renner and Beversdorf (2010) may have been false positives introduced by early onset Cortisol increases from anticipatory stress or the extended 30-minute period of the 'acute' stressor, and therefore not genuine SNS reactions. The resulting uncertainty raised by the latter study highlights the importance of collecting data when each stress pathway is active.

Specific focus on an individual pathway is not limited to SNS research. Many HPA-Axis studies have ignored more immediate autonomic responses in their attempt to link Cortisol to cognitive change. Schoofs et al. (2009) measured the effects of cold pressor stress on working memory and found that executive aspects of working memory

were negatively affected, but only 20 minutes after stress exposure, in line with the HPA-Axis reaction. Although Elzinga and Roelofs (2005) previously reported that working memory changes required both SNS and HPA-Axis activation, this result could not be confirmed by Schoofs and colleagues as they recorded no measure of SNS activity. Similarly, Robinson et al. (2008) reported evidence of "a dissociation between behavioural and biochemical measures" (p.115) when showing that working memory was impaired immediately following an acute naturalistic stressor (HUET), but that physiological measures only demonstrated significant change 25 minutes after the exposure. However, the experiment did not include any biomarkers for SNS reactivity, only HPA-Axis reactivity. It seems plausible that there would have been some SNS reaction.

These discrepancies emphasise the necessity of recording measurements of both SNS and HPA-Axis activity in stress research. This would elucidate what physiological pathways have been engaged, to what extent they reacted, and how responsible they might be for any cognitive changes. Of those studies that have included explicit measurements of both the SNS and HPA-Axis reactivity, there are few that have examined a single type of cognition, such as attention, with the intention of elucidating differential effects of the physiological reaction to cognitive change. Instead many researchers use the measures to validate that stress has been successfully induced. To illustrate, Scholz et al. (2009) used a Go/No-go task to measure selective attention following participants' exposure to the TSST, and recorded measures of both heart rate (SNS) and Cortisol (HPA-Axis). Both measures showed elevated levels following the TSST, however performance on the attention task was only measured between 10 minutes and 20 minutes after the TSST stressor had been completed. Although the authors justified this as capturing a period when Cortisol was likely to peak, Kirschbaum & Hellhammer (1994) have shown that this was probably too early. Furthermore, it does appear to have been a missed opportunity to measure the cognitive effects of the SNS reaction. The Go/No-go task itself takes 10 minutes to administer. Performing the task immediately post-stressor would have captured

SNS-related cognitive changes, with a subsequent testing session likely acquiring any changes related to the ongoing HPA-Axis activity. This seems particularly important considering some studies have found disparity between the SNS and HPA-Axis reactions when investigating the effects of stress on selective attention.

As an example of conflicting findings regarding the effect of stress on selective attention, the Braunstein-Bercovitz (2003) and Roelofs et al. (2007) studies reviewed earlier can be compared. In the case of Braunstein-Bercovitz (2003), the attention task was performed immediately following stress and lasted approximately 15-20 minutes. This timescale would strongly suggest that poorer selective attention was due to the activity of the SNS reaction rather than the HPA-Axis, which would not yet have increased Cortisol to peak levels. Conversely, Roelofs et al. (2007) took measures of the HPA-Axis response and described Cortisol responders as improving vigilance towards negative stimuli and exhibiting less interference from non-salient stimuli, thus showing improved selective attention. Selective attention was poorer or improved, depending on the time since stress.

Evidently, the physiological pathway active following exposure to acute stress appears to have the potential to alter cognitive capabilities. A potential first step to understand the interaction between the attentional networks and the physiological pathways response to stress would be to measure each of the three attentional networks within a single task. Further, this measurement could be concentrated on periods linked to the physiological responses of the SNS and HPA-Axis. One such task that might permit such a study is the Attentional Network Test, originally developed by Fan, McCandliss, Sommer, Raz and Posner (2002) and updated by Fan et al. (2009).

1.6 The Attentional Network Test

The Attentional Network Test (ANT) was initially developed in an attempt to evaluate the three attentional networks hypothesised by Posner and Petersen (1990) in a single testing session. The task itself is a combination of a cued reaction time task (Posner,

1980) and an Eriksen flanker task (Eriksen & Eriksen, 1974). Participants are expected to respond to the direction of a central arrow (left or right) which is presented either above or below fixation. The central arrow is flanked by distractors (four congruent or incongruent arrows) or neutral lines and follows a series of cue conditions (no cue, centre cue, double cue or spatial cue). Difference scores are calculated using different cue types and flanker conditions and allow for a series of efficiency measures for each of the three networks.

A large number of studies have employed the ANT and its various iterations due to its ease of use and its simplistic methods of calculating network efficiency. For instance, Jennings, Dagenbach, Engle and Funke (2007) examined age-related changes in attention, comparing 18 to 21 year olds with high functioning seniors (61-87 yrs). The results showed that advanced age reflected weaker alerting efficiency and poorer executive control. Other studies have used the ANT to examine clinical patients with Borderline Personality Disorder (Klein, 2003; Rogosch & Cicchetti, 2005), Schizophrenia (Wang et al., 2005), Depression (Murphy & Alexopoulos, 2006) and Alzheimer's disease (Fernandez-Duque & Black, 2006). Additionally, some have investigated how the performance of the attentional networks is moderated by individual factors such as working memory (Redick & Engle, 2006), personality (Gómez-Íñiguez et al., 2014; Matthews & Zeidner, 2012) and bilingualism (Marzecová, Asanowicz, Krivá, & Wodniecka, 2013).

Despite the ANT's simplicity which led to a rapid rise in the popularity of the tool, it has been criticised for not considering the possible interactions between the three attentional networks. As a result, several reviews were published critiquing the ANT, assessing both its reliability and validity. One such review, published by Macleod et al. (2010) stated that the ANTs use of well-established cueing and flanker tasks allowed a certain level of validity. The authors also reported a series of studies that had observed the ANT to have high construct validity (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Ishigami & Klein, 2010). However, the review also recommended a level of caution

when using the tool as reported reliability levels are often only moderate, even in the largest studies. Macleod et al. (2010) implied the blame lies with the use of difference scores, which have low reliability "as a result of the inverse relation [with] the correlation between the two variables used in creation of the difference score" (Salthouse & Heddon, 2002, as cited in Macleod et al. (2010)). The review also repeated the criticism that prior assumptions of network independence were erroneous, as several studies have demonstrated interactions between the networks (Costa, Hernández, & Sebastián-Gallés, 2008; Oberlin, Alford, & Marrocco, 2005; Redick & Engle, 2006), whilst neuroimaging studies have shown the attentional networks are not anatomically distinct and therefore likely to interact (Corbetta & Shulman, 2002).

In response, Fan et al. (2009) developed a revised version of the task, the ANT-Revised (ANT-R). Fan reduced the number of cue types from four to three (no cue / double cue / spatial cue) and removed the neutral condition (leaving only congruent and incongruent). They also manipulated spatial cue validity to measure reorienting and disengaging operations, as well as cue-target intervals to test for effects of alerting on conflict processing. Finally, they included location congruency (Simon effect - Simon & Wolf, 1963) to test for effects of both flanker and location conflict (Fan et al., 2009, p.222). A subsequent review by Ishigami et al. (2016) suggested higher levels of reliability.

Several studies have employed the Attentional Network Tests to examine alterations to network performance in response to various types of distress. One example is the work by Finucane and Power (2010) who used affective pictures to elicit a state of fear. The results showed that those who reported greater levels of fear, also demonstrated enhanced executive control network efficiency, indicated by shorter reaction times and better inhibition of distracting stimuli. Leskin and White (2007) instead used the tool to explore chronic stress, specifically Post-Traumatic Stress Disorder (PTSD). In this study, the authors compared individuals diagnosed with PTSD against individuals who had

encountered significant trauma but did not meet the criteria for PTSD, and a group of low trauma controls. The results showed that PTSD sufferers' executive control was significantly compromised when compared to the other two groups. Despite the above evidence demonstrating that distress, altered affective state or exposure to stress long-term can cause alterations to attentional network efficiency, there appears to be no existing work using the ANT or ANT-R in an acute stress measurement paradigm.

1.7 Research Aims

There are a number of factors contributing to the inconsistencies of stress research. The current programme of study intends to examine attentional networks which are hoped to offer a better understanding of how stress affects different aspects of attention.

Further, the magnitude of an individual's response to stress exposure is of paramount importance when attempting to understand the potential impact on cognitive change. Regardless, many studies fail to directly examine the influence of individual factors such as appraisal and physiological reactivity on observed cognitive changes. Instead, much research appears satisfied that any demonstrable increase in self-report or physiological measures demonstrates that stress has been experienced, before limiting examination to differences between stress and control groups. For this reason, the current work will aim to not only understand how self-report and physiological measures are altered following stress, but also to understand whether the higher levels of physiological activity directly influence alterations to cognitive performance.

The magnitude of stress response, and therefore (potentially) the influence on cognition, is driven by two inter-related factors; the task employed to induce acute stress, and how much time has elapsed between stress and testing cognitive performance. Although many laboratory tasks have been validated as inducing acute stress, those with rapid administration such as the cold pressor paradigm offer the clearest opportunity to

narrowly constrain and identify the point of exposure. Therefore, they also offer the best opportunity to accurately measure how cognitive performance is altered in relation to the time course of stress with regard to the known physiological responses. For this reason, the current series of experiments will use a rapid stressor, the SECPT, in order to examine the importance of time-course on the effects of stress on cognitive performance. Specifically, it is hoped to provide a more consistent account of the influence of stress on attention than currently available from the literature.

2 Pilot Study

2.1 Chapter Overview

An extensive body of work has examined the effects of acute stress on attention. However, Chapter One illustrated how the results of this work often appear to contradict. Various researchers have demonstrated that attention can be enhanced or diminished following acute stress, whilst others have argued it imparts little influence. Several explanations for this complex landscape of findings have been proposed. The purpose of the current chapter is to report the outcome of a pilot study that trialed a new experimental procedure designed to account for these factors while exploring the influence of stress on visual attention.

2.2 Design Proposal

Given the arguments in Chapter One, the following design parameters were proposed for future studies: 1) Participants should perform an attention task capable of capturing multiple attentional effects concurrently to enable the best representation of real world attentional needs; 2) In order to adequately understand performance evolution post-stress, and offer explanations for the current conflicts, the task should be completed both immediately following exposure to acute stress, and in a delayed period; 3) Those periods should align with the time-course of the physiological reactions to stress (SNS and HPA-Axis) to examine whether magnitude of the active physiological response directly influences attentional change; 4) The stressor should rapidly induce a substantial stress response in order to clearly delineate these periods.

2.2.1 Potential Issues

The design as proposed is subject to some concerns that must be understood. First, participants are required to complete the attention task up to three times to capture baseline

performance as well as the two periods (early and delayed) post-stress. Repetitive testing may lead to participants experiencing training effects that improve performance or time on task effects (fatigue/boredom) that degrade performance. Second, the selected stressor must quickly induce a marked stress (increase state levels of stress, anxiety and workload) in order to clearly define the "post" stress period(s). Third, only the stressor, and not the cognitive tasks, should lead to a stress response to minimise any confounding effects.

2.3 Pilot Study

A pilot study was designed according to the parameters above to assess whether participants were able to both perform reliably within such an experiment and that meaningful data may be collected. For this purpose, a simple attention task was developed that incorporated a basic Posner-cuing paradigm (Posner & Cohen, 1984) with an Eriksen Flanker task (Eriksen & Eriksen, 1974). The task was based on the ANT (Fan et al., 2002), but included a greater number of trials (384 compared to 288) and was shorter in duration (15 mins), so as to be more onerous than the ANT itself. The task selected to act as the stressor was the Socially Evaluative Cold Pressor Task. Similar to the Cold Pressor Task, the SECPT can be administered in three minutes and has been shown to reliably induce effects of stress (Schwabe et al., 2008). However, the SECPT also introduces a psychosocial component which should act to increase the impact of the stressor. Successful induction of stress was assessed using the Spielberger State Anxiety Index (SSAI) and a modified NASA-TLX to explore task workload and subjective stress state. Participants also completed a measure of coping (Coping Inventory for Task Stress–Situational – CITS-S) to provide a more complete understanding of participants appraisal of the stressor and how individual differences impact experiences of stress exposure.

The purpose of the pilot work was to ascertain whether participants could successfully complete an intensive, repetitive task, with relatively stable performance and to ensure the efficacy of the selected stressor. Performance on the attentional task was

assessed using global accuracy and response times (RTs). This provided an indication of stable performance over multiple iterations.[2]

The following hypotheses were submitted for the pilot study:

1a. Exposure to the SECPT would increase state anxiety compared to controls and lead to higher levels of workload.

1b. Completion of the attention task itself (and other scales of measurement) would not contribute to stress state (as measured by workload).

2. Coping (in particular task-focused coping) would be higher amongst stress participants than controls.

3. Participants performance would remain relatively stable across three repeated instances of the attention task, as assessed by global accuracy and RT.

2.4 Method

2.4.1 Participants

Twenty-eight healthy men and women ($\bar{x}$ *age* = 19.96 yrs, *SD* = 2.8 yrs) were randomly assigned to either a control group (Warm Pressor Task: n = 14, [12 female], $\bar{x}$ age = 20.14 yrs, *SD* = 2.54 yrs) or a stress manipulation group (SECPT: n = 14, [11 female], $\bar{x}$ age = 19.79 yrs, *SD* = 3.12 yrs) using a randomised block design. Participants were students at the University of Southampton and recruited via the university's online research portal or on-campus advertisements. Participants provided written informed consent and upon termination of their final session were compensated with a maximum of £12, or credits towards partial fulfilment of their course requirements.

[2] It is possible to compute various ANT-type measures from the experimental data. The raw data (minus exclusions) including demographics, accuracy and RT are attached in Appendix A and made available for analysis.

2.4.2 Exclusions

Exclusionary criteria were provided on recruitment adverts and participants were not permitted to participate if any of the following were true: i) current smoker, ii) regular smoker within the previous 12 months, iii) history of poor circulation, iv) diagnosis or history of any psychiatric or neurological illness/impairment, v) diagnosis or history of any anxiety or depression based-illness/disorder. Compliance was checked by the experimenter during the first of two sessions. Additionally, females were asked to attend their second session during the luteal phase of their menstrual cycle (i.e. the 2-14 days prior to commencing their period). This was to account for known differences in females hormone levels that are able to affect the stress response (Kudielka & Kirschbaum, 2005). Finally, a minimum level of accuracy to be achieved on each participants first (baseline) attention task was established at 90 %, in line with other similar attention studies (Fan et al., 2009, 2002).

2.4.3 Apparatus and Procedure

For detailed explanations of the following tasks, including the specifics of their administration, please see Chapter Three – Methodology.

2.4.4 Stress Induction

The Socially Evaluative Cold Pressor Task was selected for its rapid administration (3-5 mins). Participants immerse their hand in cold water (~ 3°C) for a maximum duration of three minutes, whilst under the belief that their facial expressions are being recorded to be compared against other participants. No filming takes place; however, the belief is sufficient to induce a psychological threat to the participants. Conversely, control participants immerse their hand in warm water (~37°C) for 3 minutes, with no camcorder present.

2.4.5 Psychosocial and Working Memory Assessments

2.4.5.1 Anxiety

Participants completed Spielberger's Trait/State Anxiety Index (Spielberger, 1966) and the Intolerance of Uncertainty scale (IUS-12 - Carleton, Norton, & Asmundson, 2007).

2.4.5.2 Workload

A modified version of the NASA-TLX visual analogue scale (Hart & Staveland, 1988) was used. The modification was the addition of a seventh scale that explicitly captured how "stressed" participants felt.

2.4.5.3 Coping

The Coping Inventory for Task Stress – Situational (CITS-S) was used to measure coping strategies participants employed when undertaking the SECPT or control task (Matthews & Campbell, 1998).

2.4.5.4 Working Memory

Participants completed a spatial and verbal 3-Back task, each lasting approximately eight minutes (Shackman et al., 2006). Copies of the aforementioned scales are available in Appendix B.

2.4.6 Attention Task

A simple attention task, based on the ANT was designed to explore the 'cue validity' effect and the 'flanker' effect following acute stress.

2.4.6.1 Apparatus

The task was administered using a Viglen 800S computer running Windows 7 Enterprise and viewed on a Mitsubishi Diamond Plus 92 19-inch CRT monitor. The refresh rate was 85 Hz with a resolution of 1280 x 1084 pixels. Participants sat in a dimly lit room approximately 60 cm from the monitor and responses were collected using the left- or right-hand keys of a Cedrus RB-730 response pad connected via USB port. The task was programmed using SR Research's Experiment Builder.

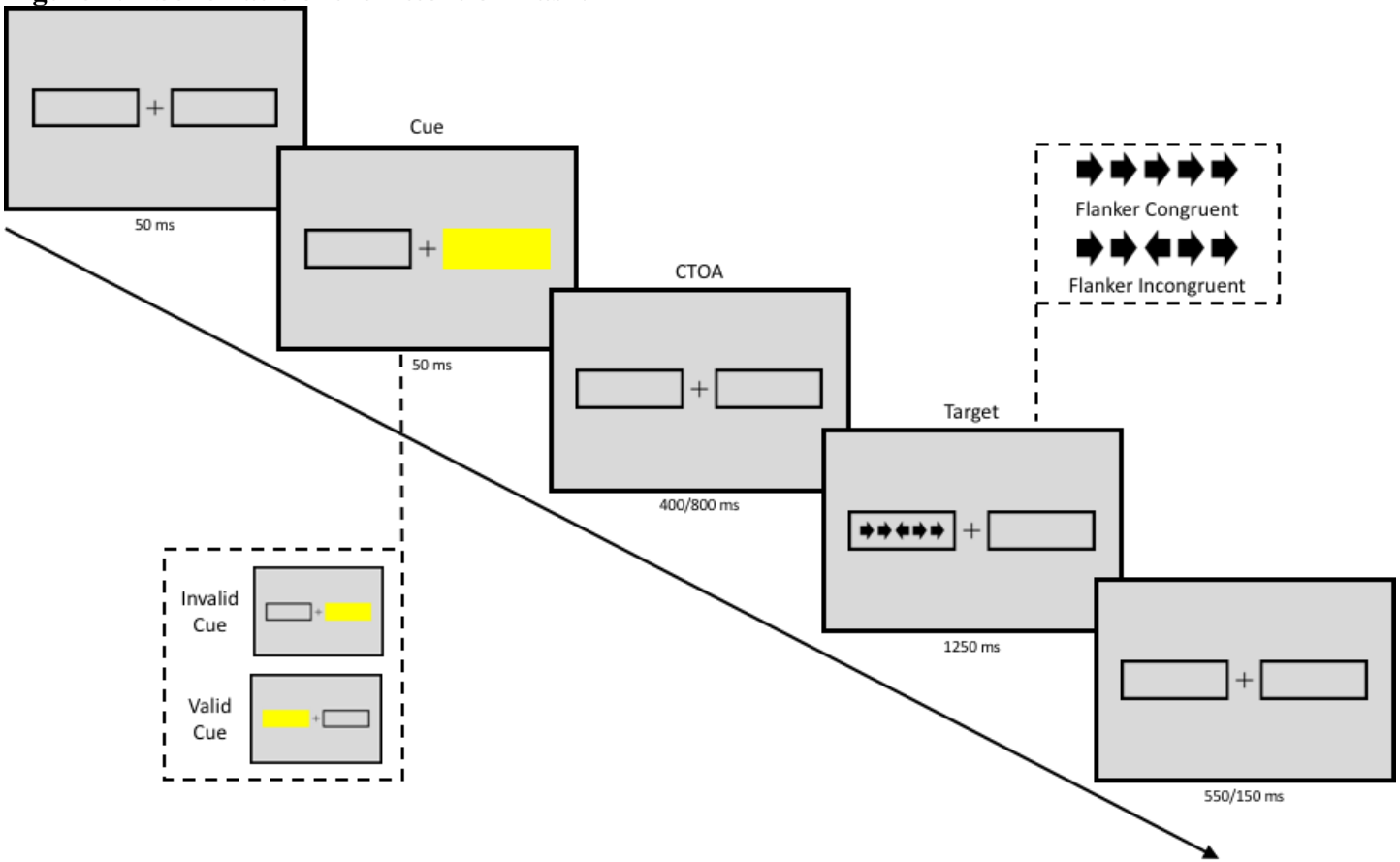
2.4.6.2 Stimuli

The stimuli comprised of two rectangle outlines presented either side of a central fixation cross, against a grey background. Each trial, one rectangle flashed yellow (cue) before a target appeared inside that rectangle (valid trial) or the other (invalid). The target was a left- or right-facing arrow in the centre of the rectangle, with two additional arrows each side of the target, acting as distractors and facing the same (congruent) or opposite (incongruent) direction. The central fixation cross subtended 1.15 x 1.15 degrees/visual angle, the rectangles subtended 5.25 x 2 degrees and each arrow subtended 0.85 x 0.95 degrees, with 0.1 degree of separation between each arrow. Participants maintained gaze at the central fixation whilst identifying the direction of the target as quickly as possible. Participants selected their answer by pressing a left or right keyboard button, using their left index finger for left-facing arrows, or right index finger for right-facing arrows.

2.4.6.3 Design

The attention task was performed a total of three times (tranches) during the experiment. Each tranche lasted approximately 15 minutes and comprised three blocks, each separated by a 'break' screen. Blocks totalled 128 trials, therefore participants completed 384 trials per tranche, and 1152 trials over the experiment. Each trial began with the presentation of a fixation cross, flanked by two rectangles, for 50 ms. One rectangle flashed yellow for 50 ms, before the rectangles returned for a randomised Cue-to-Target Asynchrony (50 % of trials at 400 ms / 50 % at 800 ms). A target was then presented and remained visible for a maximum of 1250 ms, or until the participants responded. Following the response (or time out), the rectangles returned for either 550 ms or 150 ms (depending on SOA), in addition to any time remaining of the 1250 ms. Each trial lasted a total of 2300 ms (see Figure 2.1). The validity of the cue was evenly split between valid and invalid, with flanker congruency also equally split between congruent and incongruent. The target was presented inside each rectangle an equal number of times.

Figure 2.1 Schematic of the Attention Task.



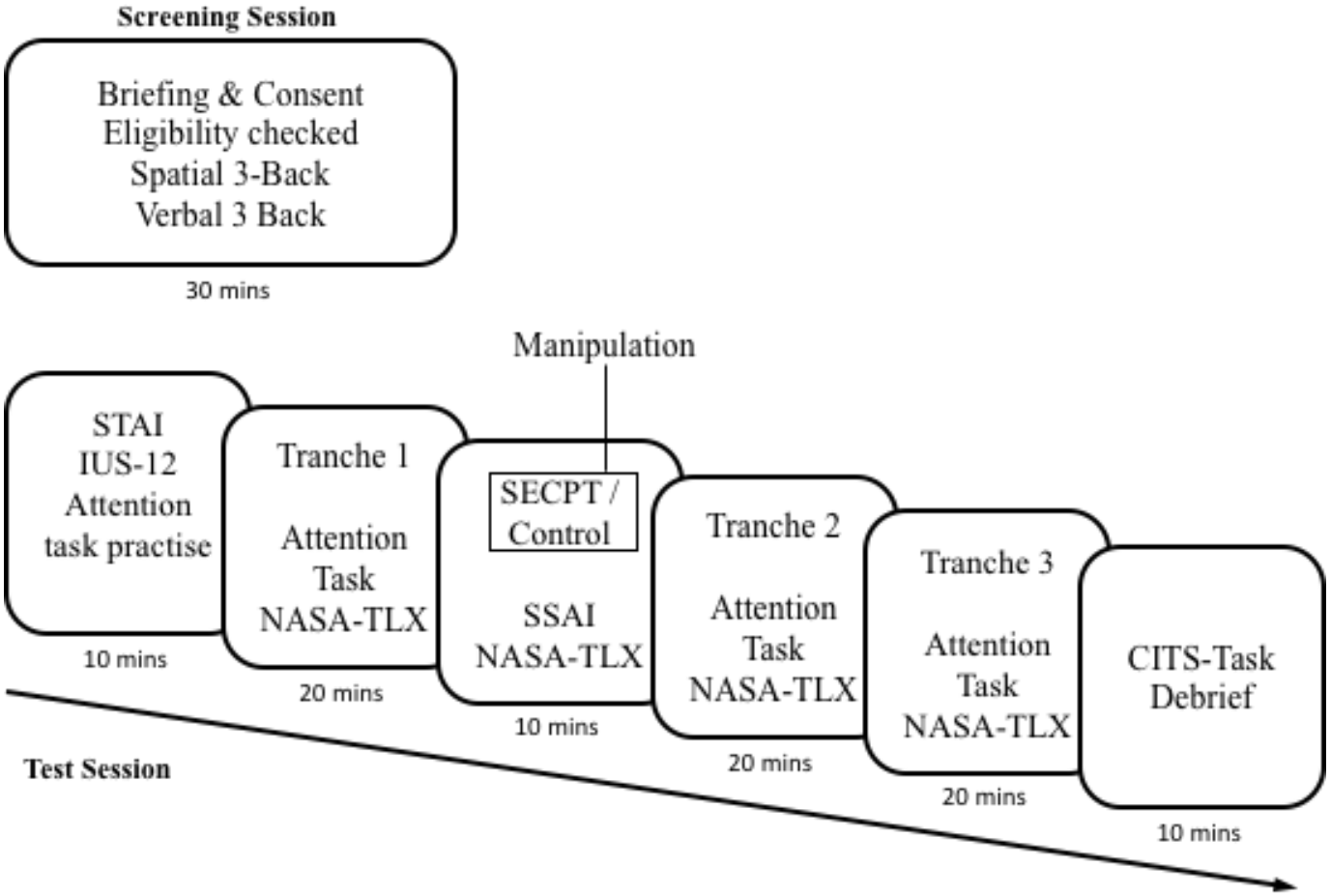
Each trial lasted 2300 ms and consisted of a fixation display, followed by a cue and a variable Cue-to-Target Onset Asynchrony (CTOA), before the target appeared flanked by four arrows. Participants had a maximum of 1250 ms to respond. The above trial depicts an invalid cue, in an incongruent flanker condition (not to scale). Figure 2.2 Runtime order for Pilot Study.

2.4.7 Procedure

Having registered to take part, participants attended a 30-minute screening session at either 12:00 or 12:30 receiving a thorough written and verbal briefing, before providing informed written consent. Compliance with eligibility criteria was checked by the experimenter and basic demographic information recorded before participants completed the spatial and verbal 3-Back tasks (Shackman et al., 2006). Participants then booked to attend a follow-up test session within three weeks, with females asked to attend during the luteal phase of their menstrual cycle.

Follow up sessions began at one of four times: 09:00, 10:30, 13:00, or 14:30. Upon arrival participants completed measures of trait anxiety (STAI) and Intolerance of Uncertainty (IUS-12), before completing a short practice version of the attention task, lasting 3 minutes. Participants then completed tranche one (Baseline) of the attention task (384 trials), followed by their first workload measure (modified NASA-TLX). Immediately following this, participants completed the stressor manipulation (SECPT) or comparable control task (warm water) before completing another NASA-TLX, as well as a measure of state anxiety (SSAI). They then commenced tranche two (Early) of the attention task. When complete, participants filled in their third NASA-TLX and before completing tranche three (Delayed) of the attention task. Participants then completed their final NASA-TLX, as well as the CITS-S, providing a measure of the coping strategies they employed during the SECPT or control task. Finally, all participants received a thorough debrief and compensation for their time (see Figure 2.2).

Figure 2.2 Runtime order for Pilot Study.



Participants attended a 30-minute screening session, before returning for a test session no more than three weeks later. The test session began at one of four times (09:00 / 10:30 / 13:00 / 14:30) and lasted no more than 90 minutes.

2.5 Results

2.5.1 Exclusions

Data from six participants were excluded prior to analysis for failing to reach the 90% accuracy threshold during their baseline attention task (tranche one). Unfortunately, all six had been assigned to the control condition, leaving the groups of unequal size. Consequently, the control group had eight participants (7 females; $\bar{x}$ *age* = 20.25 yrs, *SD* = 2.87 yrs), and the stress group had 14 participants (11 females; $\bar{x}$ *age* = 19.79 yrs, *SD* = 3.12 yrs).

2.5.2 Analysis Design

Analyses were conducted in three parts: 1a) self-reported anxiety and workload measures were examined to check the efficacy of the stress manipulation, 1b) those anxiety and workload measures were further checked to ensure the task/design itself was not contributing to experiences of stress, 2) levels of coping were compared between groups, and 3) global attentional performance (accuracy and RT) were examined for stability across iteration (tranches).

Degrees of freedom were corrected to Greenhouse-Geisser when the assumption of sphericity was violated. Effect sizes for ANOVAs are reported as partial η^2, whilst t-tests are reported as Cohens *d* (t-tests) unless excessive variation of standard deviations (Glass's *Delta* Δ) or sample size (Hedges *g*). The raw data is available in Appendix A.

2.5.3 Anxiety and Workload

An independent samples t-test showed a significant difference between groups for state anxiety (SSAI) immediately following the stressor/control manipulation ($t(18.19) = -4.31$, $p < .001$, Hedges $g = 1.54$). This indicates that participants who undertook the SECPT reported their experience as causing significantly higher anxiety than participants who had undergone the comparable control task.

A series of 2 (Condition: Stress vs Control) x 4 (Time-point: T1 to T4) repeated measures ANOVAs were performed on the seven (modified) NASA-TLX measures, with an interaction of Condition x Time-point of interest. Significant interaction effects were observed for all seven measures (all F's > 4.20, all p's < .009, partial η^2's > .173). Planned comparisons using independent samples t-tests revealed a significant difference at T2 (i.e. immediately following the stressor) for each measure (all p's < .002, all Hedges g > 1.29). Importantly each difference appeared in the expected direction; stress participants rated their performance lower, but reported higher ratings for all other measures (T2 means are shown in Table 2.1). For each measure, differences at all other time-points did not reach significance (all p's >.088), indicating that the attention task itself did not contribute to overall stress state.

Table 2.1 *Pilot study: Mean (SD) ratings by participants on Spielberger State Anxiety Index (SSAI – scores 0-80) and NASA-Task Load Index (scores 0-100) immediately following stress exposure or control (T2).*

		SSAI	Mental	Physical	Temporal
Condition	*n*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	8	32.25 *(3.99)*	3.25 *(6.52)*	10.63 *(7.82)*	3.88 *(6.79)*
Stress	14	45.86 *(10.57)*	36.07 *(31.13)*	76.71 *(25.13)*	32.57 *(26.9)*

		Performance	Effort	Frustration	Stress
Condition	*n*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	8	93 *(11.43)*	19.25 *(31.65)*	2.13 *(2.3)*	3 *(3.34)*
Stress	14	37.07 *(39.15)*	69.43 *(28.80)*	42.43 *(33.22)*	49.79 *(28.64)*

2.5.4 Coping Strategy

A total coping score for each participant was calculated by summing their scores across each subset of the CITS-S which includes task-, emotion-, and avoidance-focused coping (see Table 2.2). An independent samples t-test demonstrated that although stress participants ($\bar{x}$ = 29) scored higher overall than control participants ($\bar{x}$ = *22)*, the difference did not reach significance ($t(20) = -1.53$, $p = .143$, Hedges $g = .68$). Similar independent

samples t-tests were performed for each subset of the CITS-S and again indicated that although coping scores were higher for stress participants for each type of coping, their level was not significantly higher than control participants (all t's < 1.43, all p's > .169, all Hedges g's < .63).

Table 2.2 *Pilot study: Mean (SD) ratings by participants on Coping Inventory for Task Stress – Situational, examining their use of coping strategies following stress exposure or control.*

		Total Coping	Task-focused	Emotion-focused	Avoidance-focused
Condition	*n*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	8	22.00 *(10.14)*	12.88 *(5.11)*	4.75 *(5.75)*	4.38 *(5.13)*
Stress	14	29.00 *(10.47)*	15.71 *(4.12)*	6.64 *(5.85)*	6.64 *(5.02)*

2.5.5 Attentional Performance

2.5.5.1 Test-Retest Reliability

To check the reliability of the attention task across repeated iterations, correlations of global accuracy and RT across the three tranches was checked for all participants. Global accuracy was significantly correlated across all time-points (tranches) (all r's > .892, all p's < .001). Similarly, global RT was significantly correlated across all time-points (tranches) (all r's = .703, all p's < .001) (see Table 2.3). This demonstrates that performance on the attention task was consistent across the three iterations of the task indicates good reliability.

Table 2.3 *Pilot study: Correlation matrix for global accuracy (a) and RT (b) across three time-points (Baseline / Early / Delayed).*

(a)

		Global Accuracy	Global Accuracy	Global Accuracy
		Baseline	Early	Delayed
Global Accuracy	Pearsons *r*	1	.945*	.892*
Baseline	Sig. (2-tailed)	1	.000	.000
Global Accuracy	Pearsons *r*		1	.938*
Early	Sig. (2-tailed)		1	.000
Global Accuracy	Pearsons *r*			1
Delayed	Sig. (2-tailed)			1

(b)

		Global RT	Global RT	Global RT
		Baseline	Early	Delayed
Global RT	Pearsons *r*	1	.870*	.703*
Baseline	Sig. (2-tailed)	1	.000	.000
Global RT	Pearsons *r*		1	.922*
Early	Sig. (2-tailed)		1	.000
Global RT	Pearsons *r*			1
Delayed	Sig. (2-tailed)			1

* Correlation is significant at the 0.001 level

2.5.5.2 Global Accuracy and RT – Groups

A 2 (Condition: Stress vs Control) x 3 (Tranche: Baseline / Early / Delayed) repeated measures ANOVA was also performed to understand how accuracy changed over three iterations of the task, and whether there were any group differences. There was no main effect of time (p = .114) and no interaction of Condition and Tranche (p = .972 – see Table 2.4), indicating that task accuracy remained constant throughout repeated iterations and did not differ between condition (see Figure 2.3).

Figure 2.3 Global accuracy rate across three time-points.

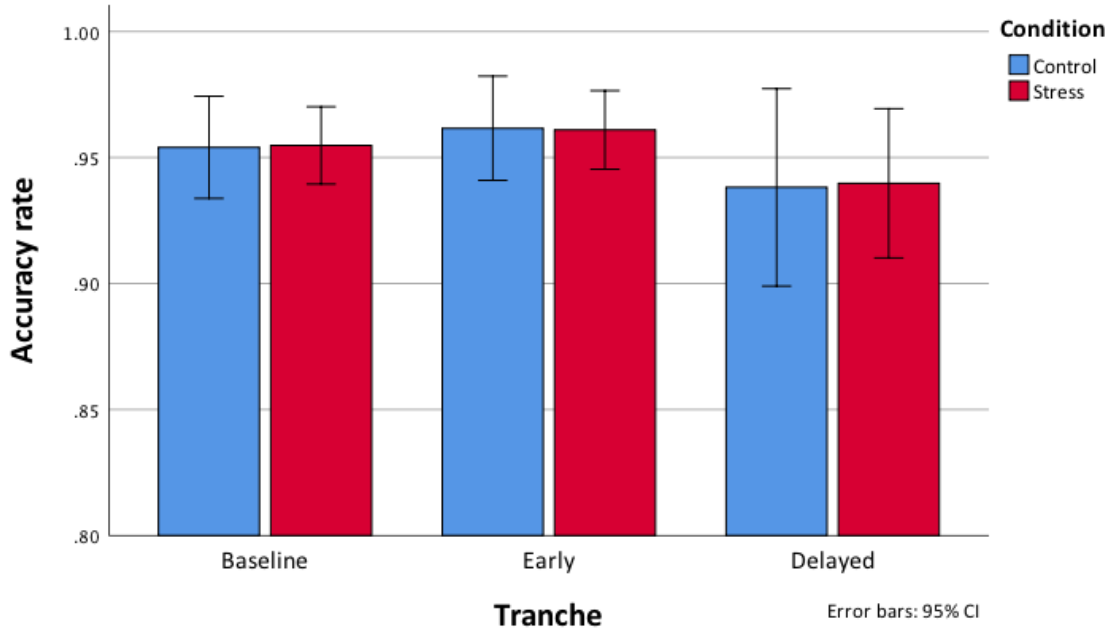


Figure 2.3 Graph demonstrates accuracy rate remained stable across three iterations of the task, regardless of Condition.

An identical 2 x 3 repeated measures ANOVA was performed to explore how RT changed over iterations of the task (see Table 2.4). There was main effect of Tranche ($F(1.37,27.45) = 26.42$, $p < .001$, partial $\eta^2 = .57$), with paired samples t-tests indicating that RT appeared to improve successively with each iteration (Baseline to Early: ($t(21) = 6.30$, $p < .001$, $d = .53$), Early to Delayed: ($t(21) = 1.83$, $p = .082$, $d = .11$), *also* Baseline to Delayed: ($t(21) = 5.7$, $p < .001$, $d = .64$)) (see Figure 2.4).

Additionally, there was a weak interaction of Condition and Tranche ($F(1.37,27.45) = 3.11$, $p = .077$, partial $\eta^2 = .14$). Paired samples t-tests exploring each condition separately demonstrated that whilst controls improved performance between their Baseline and Early tranches ($t(7) = 4.50$, $p = .003$, $d = .34$), they did not continue to improve from Early to Delayed ($t(7) = -.246$, $p = .812$, $d = .01$). On the other hand, stress participants appeared to improve their RT with each iteration (Baseline to Early: ($t(13) = 5.19$, $p < .001$, $d = .64$), Early to Delayed: ($t(13) = 2.26$, $p = .041$, $d = .2$)) (see Table 2.4). This shows that performance speeded across iteration, but reached significance in the stress group across all time-points. However, due to the unequal group sizes the power to detect

Figure 2.4 Global RT rate across three time-points.

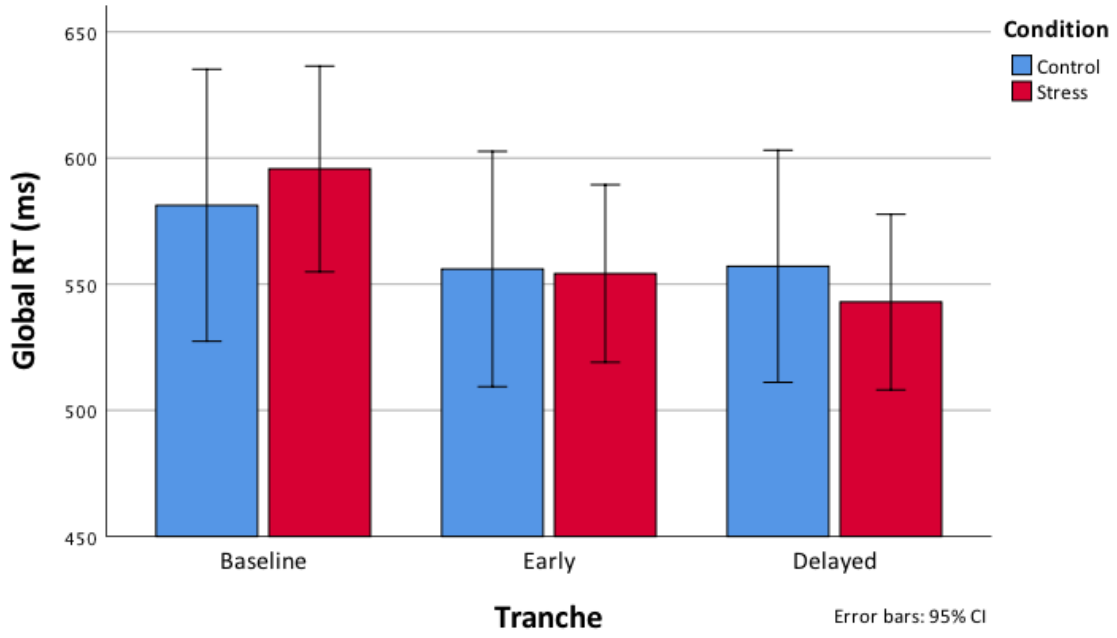


Figure 2.4 Graph demonstrates RT speeded with each iteration for stress participants, but only between baseline and early for controls, indicative of a practice effect.

an effect is different, therefore any conclusion that stress led to a consistent speeding of response should be treated with caution.

Table 2.4 *Pilot study: Means (and Standard Deviations) of global accuracy and RT for both Control and Stress participants across three time-points (Baseline / Early / Delayed).*

			Baseline	Early	Delayed
	Condition	*n*	Means *(SD)*	Means *(SD)*	Means *(SD)*
Global Accuracy *(%)*	Control	8	95.4 (3.27)	96.16 (2.4)	93.82 (4.36)
	Stress	14	95.48 (2.43)	96.09 (2.3)	93.97 (5.76)
	Total	22	95.45 (2.69)	96.12 (2.73)	93.92 (5.18)
Global RT *(ms)*	Control	8	581.26 *(76.24)*	556 *(71.01)*	557.08 *(75.66)*
	Stress	14	595.7 *(71.38)*	554.22 *(58.55)*	542.92 *(53.92)*
	Total	22	590.45 (71.71)	554.87 (61.68)	548.07 (61.29)

2.6 Discussion

The present pilot study examined the feasibility of an iterative attention study following exposure to an acutely stressful experience. Stress was induced via the SECPT

and assessed using self-reported state anxiety and workload measures. In line with expectations, participants who experienced the SECPT immediately reported significantly higher levels of state anxiety than their control counterparts. Similarly, workload measures showed that following the manipulation, stress group participants experienced greater levels of effort, demand, stress and frustration, as well as lower levels of performance satisfaction, than participants in the control group. These results offer support for the original hypothesis that exposing a participant to the SECPT would induce a 'stressed' state, providing support for the use of the SECPT in future empirical work. Furthermore, those same workload measures, across all participants, revealed no significant differences at any other time-point. This shows that completing the attention task became no easier nor difficult, despite multiple iterations of the task. This was of particular concern as exposure to the SECPT could have resulted in participants perceiving the post-stress attention tasks as more difficult, as a result of legacy stress effects.

Additionally, it was hypothesised that those participants exposed to the SECPT would demonstrate higher levels of coping, particularly task-focused coping, than controls, as they appraised the SECPT as more stressful than the control task. Measured using the CITS-S coping scale, stress participants indicated higher overall coping scores, and higher scores for each subset (task-, emotion- and avoidance-focused), although contrary to expectations these scores were not statistically significantly higher than controls. A possible explanation for this could be that as completion of the SECPT is both rapid (~ 3minutes) and relatively simple, participants did not have enough time, or need to construct an appropriate strategy for successful completion. Alternatively, due to time constraints participants were only asked about their coping strategies at the end of the experimental session, when they might have forgotten about their use of any strategy. Future studies that use the SECPT will ask participants to be mindful of their thoughts during the task as they will be asked about them at the end of the study.

The attention task provided good test-retest reliability with respect to accuracy and RTs across iterations. Furthermore, analyses of variance demonstrated that global accuracy was stable across three iterations of the task, regardless of condition. Interestingly, for global RT, participants demonstrated a small, but significant speeding of response across the three iterations of the task. Perhaps somewhat problematically, there was a trend towards an interaction between condition and the attention tasks for RT. Interpreting this interaction is difficult given the loss of participants from the control group. However, a conservative conclusion is that RTs in the attention tasks may speed over iterations, and that this speeding might be influenced by stress.

2.6.1 Limitations

The selection of the SECPT to induce stress was constrained by several factors important to the current study. Recent definitions of stress consider it necessary to employ a stressor that is perceived as unexpected and uncontrollable, which the SECPT satisfies. However, perhaps more important for the current aims was the ability to administer the task quickly (~ 3 mins), as the work looks to examine how the effect of stress evolves over time from exposure. Other common psychosocial stressors, such as the Trier Social Stress Test (TSST), produce larger impacts of stress but can take as long as 15 minutes to administer, which would make it difficult to understand when peak stress occurred, and thus identify suitable periods concurrently aligned with a physiological reaction (see below). The Cold Pressor Task, another validated psychosocial stressor could have been selected as it also takes approximately 3 minutes to administer, however it lacks any social evaluation which might induce psychological stress and it has been shown to elicit a weaker response than the SECPT (Schwabe et al., 2008). Therefore, the SECPT was selected with the expectation that the socially evaluative component would lead to a more intense experience of stress, even if it might be expected to fall short of the magnitude induced by the TSST (Skoluda et al., 2015).

A large body of existing literature has examined the physiological response to stress and identified two discrete pathways, the Sympathetic Nervous System (SNS) and the Hypothalamic-Pituitary-Adrenal Axis (HPA-Axis) (Herman & Cullinan, 1997). It is well understood that whilst the SNS is active for roughly the first 15 minutes, the HPA-Axis engages approximately 25 minutes post-exposure and can remain active for several hours (Kirschbaum & Hellhammer, 1994). Therefore, it was important to employ a stressor which permitted rapid administration, in order to reduce any possible confounding of these two discrete pathways. However, due to nature of this pilot study, it was not viable to include the collection of physiological measures. Future work should attempt to measure physiological reactivity to stress exposure in order to 1) provide additional evidence for successful stress induction, and 2) allow the researchers to confirm whether periods of testing align with the activation of these two pathways. Physiological and neurochemical changes initiated by activation of these discrete pathways could be a driving force behind the cognitive change, rather than simply time from exposure, and this should be of significant interest to future research.

One factor that might have contributed to the existing conflict evident across stress research is the numerous types of attention tasks that have been employed (see Chapter One). Whilst the present study chose to utilise a bespoke attention task, its design did rely upon two well-established and validated paradigms, namely Posner Cuing and Erikson Flanker tasks (Eriksen & Eriksen, 1974; Posner & Cohen, 1984). Correlations examining global accuracy and RT indicated strong test-retest reliability, thus supporting the use of such a task. However, in future it would be advantageous to draw from the established collection of attention tasks that are better understood and reviewed across the literature and that are readily available for download/use by researchers. One such example would be the Attentional Network Task, designed by Fan and colleagues (2002), of which the current design shares several similarities. Additionally, the ANT would allow examination

of multiple aspects of attention within a single task, satisfying another aim of the current research.

2.6.2 Conclusion

The intention of the present pilot study was to examine the feasibility of a novel design for future work exploring stress and attention. Our results show that despite the requirement for participants to complete multiple iterations of an attention task, they were able to perform all tasks effectively. Response time did improve over each iteration by a small, yet significant, margin but this did not influence accuracy rate. This indicates that although participants experience some benefits of practice, accuracy and importantly, engagement, remained high. Furthermore, the study shows that whilst the inclusion of a stressor task (SECPT) is able to induce a significantly stressful experience, as indicated by various self-report measures, the repetitive nature of the design itself does not contribute to stress state at other time-points throughout the session. Despite clear indication that exposure to the SECPT is more stressful than a control variant of the task, participants did not have to engage in significantly different (or greater) coping management strategies than their control counterparts. Taken together, the results provide good support for the implementation of such a design in future work exploring the influence of stress on attention.

3 Methodology

3.1 Chapter Overview

This chapter provides general information related to the materials and procedures subsequently applied to three empirical studies performed under this programme of study. Where required, information pertinent to specific experiments will be detailed within the relevant chapters.

3.2 Ethics

All experiments were conducted in accordance with the Declaration of Helsinki (2013) and all procedures were carried out with adequate understanding and written informed consent of the participants. All experiments (including the pilot study) were approved by both the Psychology, and the Institutional Ethics Committees at the University of Southampton. Due to their use of human saliva to obtain biomarkers of physiological activity, Experiments One to Three were also approved by the NHS, via the National Research Ethics Service.

3.3 Participants

3.3.1 Power Calculation

A power calculation was performed in order to approximate the appropriate sample size for the three proposed experiments presented in Chapters Four, Five and Six. The statistical package G*Power (v.3.1.9.3) was used to perform the power analysis. Based on the analysis of the pilot study data (Chapter Two), the selected test was a Repeated-measures ANOVA, exploring a within-between interaction (ANT-R Tranche x Condition), with the required partial $\eta 2$ set at .059 (moderate effect size, Richardson, 2011), therefore establishing an effect size *f* of 0.25. α error probability was maintained at 0.05, with power

set at 0.95, correlation among repeated measures at 0.5, and a non-sphericity correction *e* of 1. The analyses calculated the critical F output at 3.11 and the required total sample size at 44 participants, thus providing an actual power of .96.

3.3.2 Exclusion Criteria

Criteria for exclusion from the experiments included: (i) current smoker, (ii) regular smoker within the previous 12 months, (iii) history of poor circulation, (iv) active infections such as jaundice / hepatitis / haemophilia / HIV antibody positive, (v) previous diagnosis or history of any neurological illness or impairment, psychiatric illness or disorder, or anxiety-/depression-based disorders, (vi) current use of medicine used to treat anxiety or depression known to affect Cortisol levels (Kirschbaum et al., 1996). To account for known effects of chemical contraceptives on Cortisol production (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999), females using chemical contraceptives were initially excluded. This criterion was removed prior to the completion of Experiment 1 in order to facilitate recruitment and instead type of contraceptive was recorded where applicable. Regardless, all females were instructed to participate in the experiment during the *'Luteal'* phase of their menstrual cycle (i.e. 2-14 days before the start of their period) to ensure maximum Cortisol reactivity (Kudielka & Kirschbaum, 2005).

Prior to data analysis, physiological data (sAA and sCortisol) was checked and participants data removed if their basal levels were more than 2 SDs above or below the sample mean.

Additionally, a minimal level of accuracy on participants Baseline run of the ANT-R was determined using a binomial distribution calculator (https://stattrek.com/online-calculator/binomial.aspx), whereby the number of trials was 288, probability of success was 0.5, and the binomial probability was 0.01 (thus reflecting a 99 % chance the participant had engaged with the ANT-R, rather than guessed their responses). This established the minimum level of accuracy at Baseline as 159 correct responses, or an

accuracy rate of 55.2 %. This was different to the arbitrary accuracy level applied during the pilot study, and to that applied by Fan and colleagues in their paper describing the ANT-R, as 90 % was considered to be excessively onerous and thus would limit variance across accuracy data.

3.4 Experimental Materials

3.4.1 Cognitive Assessments

3.4.1.1 The Attentional Network Test – Revised (ANT-R)

Following criticisms of the original ANT (Corbetta & Shulman, 2002; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Macleod et al., 2010), the ANT-R was designed by Fan et al. (2009) to measure performance efficiencies of each of the three hypothesised attentional networks (Posner & Petersen, 1990), whilst able to account for interactions between the networks. True to the original task, the ANT-R combined a Posner cuing paradigm (Posner, 1980) with an Eriksen flanker task (Eriksen & Eriksen, 1974), whilst also introducing a Location Effect (Simon & Wolf, 1963), an Inhibition of Return measure (Posner, Rafal, Choate, & Vaughan, 1985) as well as various Cue to Target Onset Asynchronies (CTOAs) and interaction calculations.

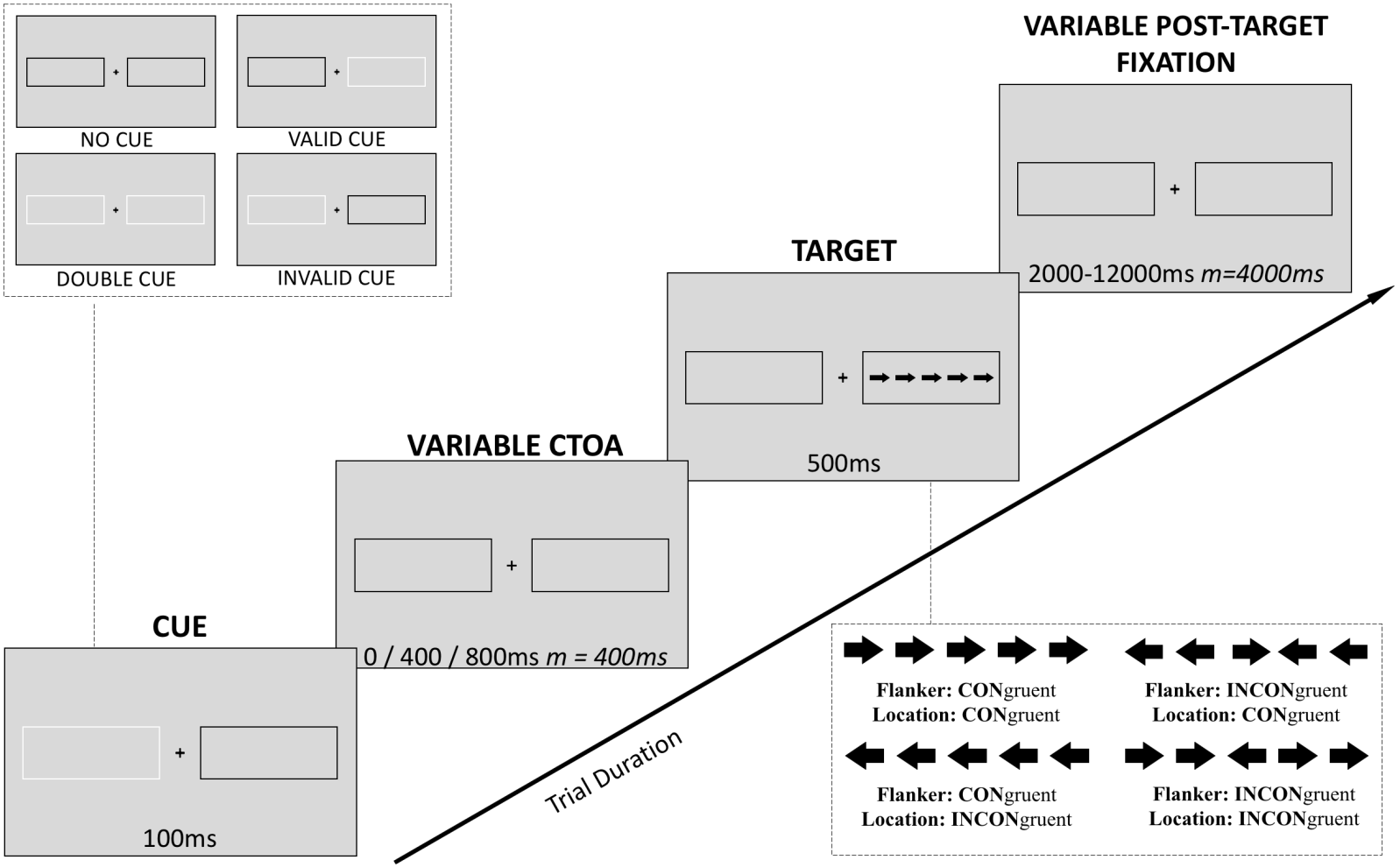
Participants indicate the direction of a central arrow, that is flanked by a series of congruent or incongruent arrows, following a range (no cue, spatial cue [both valid and invalid], double cue) of cue conditions (see Figure 3.1). Raw accuracy and response times (RT) of pairs of trial types are used to calculate difference scores measures. To illustrate, efficiency of the alerting network is derived by calculating the difference (in accuracy or RT) between trials presented with 'no cue', and trials presented with a 'double cue', where the presence of a cue leads to a more efficient response (for details see Fan et al., 2009). Difference scores have received some criticism, such as lower reliability due to the inverse relationship with the correlation of the two variables used" (Salthouse & Seddon, 2002, cited in Macleod et al., 2010). However, the task has been well validated in both healthy

and clinical populations (Antón et al., 2014; Keehn, Lincoln, Müller, & Townsend, 2010; Kubesch, Walk, Spitzer, Kammer, & Lainburg, 2009; Pacheco-Unguetti, Acosta, Marqués, & Lupiáñez, 2011) and offers an opportunity to examine multiple top-level attentional efficiencies in an acute stress paradigm. Previous research has shown that individual differences can affect attentional network performance, including age (Jennings et al., 2007), gender (Liu, Hu, Fan, & Wang, 2013), obesity (Beutel et al. 2006, *as cited in* Macleod et al., 2010) and dyslexia (Bednarek et al., 2004) whilst Redick and Engle (2006) indicated that Working Memory Capacity (OSPAN - Engle & Turner, 1989) can predict aspects of ANT performance.

Although the ANT-R has been selected for use in the subsequent experiments, for the purposes of data analysis only four measures (of a potential 15 permitted by the ANT-R) will be considered; 1) Alerting Benefit; 2) Moving and Engaging (equivalent to the 'Orienting' measure from the original ANT, and hereafter referred to as the 'Orienting Effect'); 3) Flanker Effect; and 4) Validity Effect. Measures 1-3 were selected as they offered the most robust measures, having been validated repeatedly in studies using both the ANT and the ANT-R. Measure 4 (Validity Effect) was selected following the pilot study (Chapter Two), and as it offers "an additional measure of the ability to reorient attention" (Antón et al., 2014; Fan et al., 2009). Although not considered in this thesis, raw data will be made available on the Open Science Framework in order to permit others to consider analysis of other ANT-R measures.

The ANT-R, downloaded from the original authors website (Fan et al., 2009 - http://people.qc.cuny.edu/Faculty/Jin.Fan/Pages/Downloads.aspx), was programmed in E-Prime 2.0 (SP2), version 2.0.10.356. The task was administered using a Dell Precision T3500 and Formac ProNitron 19/600 CRT monitor running Windows 7 Enterprise, with responses collected using the left- or right-hand keys of a Cedrus RB-730 response pad connected via a USB port.

Figure 3.1. Schematic of the ANT-R task



ANT-R schematic demonstrating the order of an Invalid Cue, Flanker/Location Congruent trial. CTOA – Cue-Target Onset Asynchrony. *m = mean

3.4.1.2 Working Memory – Maintenance – n-Back[3] [3]

The Working Memory maintenance task employed was the Spatial and Verbal 3-Back task designed by Shackman, Sarinopoulos, Maxwell, Pizzagalli, Lavric and Davidson (2006). The task consists of a small viewing area filled with random letters. For each trial, a smaller box that contains multiple examples of a single, random letter is presented at a random location overlaying the original image. In the Spatial version of the task, participants are asked whether the location of the smaller box is the same as three trials earlier. On the Verbal version, participants are instead asked whether the single letter (inside the box) is the same as three trials earlier. Previous work has shown the 3-Back task to have good test-retest reliability (r = .73, Hockey & Geffen, as cited in Shackman et al., 2012). The task was displayed on a 14-inch Dell Latitude E6410 laptop using Presentation software version 18.1, build 03.3.31.15, with responses collected using the left- or right-hand keys of a Cedrus RB-730 response pad connected via a USB port.

3.4.1.3 Working Memory – Complex – OSPAN

The OSPAN task as described by Unsworth, Heitz, Schrock and Engle (2005) was downloaded from the Georgia Institute of Technology's 'Attention and Working Memory Lab' (http://englelab.gatech.edu/standardtasks.html). During the task, participants are required to answer a simple maths question before being presented with a random letter. After a series of these 'trials' (between 2-7), participants need to recall each of the random letters, in order. Scores are based on how many letters are successfully recalled. The task has shown good internal consistency (alpha = .78) and test-retest reliability (.83). It was administered on the same Dell Latitude E6410 laptop as the 3-Back task, using E-Prime 2.0 (SP2), version 2.0.10.356, with responses delivered using a USB connected mouse.

[3] Previous work has shown that complex WM can predict ANT score and shield individuals from the deleterious effects of stress. Further, little work has examined how maintenance WM is impacted by acute stress. These questions fall outside the scope of the thesis but are included to provide a comprehensive account of the participants' experience.

3.4.2 Psychosocial Assessments

3.4.2.1 Karolinska Sleepiness Scale

For Experiment Three, participants completed the Karolinska Sleepiness Scale (KSS) to provide a subjective measure of sleepiness (Åkerstedt, Axelsson, Lekander, Orsini, & Kecklund, 2014; Kaida et al., 2006). The scale consists of a nine-point Likert scale, asking participants to rate their present state from "Extremely alert" (1) to "Extremely sleepy" (9). The tool is reported to be a highly valid measure of sleepiness, as it shares significant relationships with known EEG and performance measures indicative of sleepiness (Kaida et al., 2006).

3.4.2.2 Anxiety

Trait and state anxiety levels were recorded using the Spielberger Trait Anxiety Inventory (STAI) and the Spielberger State Anxiety Inventory (SSAI) (Spielberger, 1966). Each consists of 20 statements, such as "I make decisions easily" (trait) or "I feel comfortable" (state). Participants select an answer from a four option Likert scale ("not at all" to "very much so") to indicate their level of agreement with the statement. When added together, answers give a total score for trait- / state-anxiety, with higher scores reflecting higher levels of (*x*)-anxiety. Previous work has shown the state and trait scales to have high internal consistency (.91, and .89 respectively) and high test-retest reliability (.70, and .88 respectively) (Barnes, Harp, & Jung Sik, 2002; see also Quek, Low, Razack, Loh & Chua, 2004) .

3.4.2.3 Intolerance of Uncertainty

'Intolerance of Uncertainty' was measured using the IUS-12 short form (Carleton et al., 2007). Across 12 items the questionnaire poses statements such as "It frustrates me not having all the information I need", with participants required to indicate from five options how characteristic of them the statement is. Answers contribute to one of two subscales; prospective anxiety (reflecting discomfort with the unknown) and inhibitory

anxiety (reflecting uncertainty changing behaviour). Higher scores reflect higher intolerance (it is also possible to sum both scores for an overall measure of Intolerance of Uncertainty). Carleton and colleagues (2007) reported excellent reliability of the short form (Cronbach's Alpha = .94) and a high correlation with the full 27-item scale (r = .96).

3.4.2.4 Workload

The NASA-Task Load Index (NASA-TLX) employs visual analogue scales to capture subjective workload (Hart & Staveland, 1988). The original NASA-TLX used six subscales: Mental, Physical, and Temporal Demand, Performance, Effort and Frustration where participants are asked to indicate how high/low they rated the task on each measure (e.g. Mental Demand – "How mentally demanding was the task"; Performance – "How successful were you in accomplishing what you were asked to do?") . A seventh subscale, 'Stress' (Q. "How stressed did you feel?"), was added to capture an explicit, subjective measure of how stressed the participant felt whilst completing the various tasks. The tool has been extensively validated with excellent split-half reliability and Cronbach's Alpha (> .80) and good consistency across the two scales (r = .49) (Xiao, Wang, Wang, & Lan, 2005).

3.4.2.5 Coping

To capture the range of coping methods employed by participants the Coping Inventory for Task Stress was used (CITS-S – Matthews & Campbell, 1998). The scale comprises of three sub-scales; Task-focused, Emotion-focused and Avoidance-focused coping. Statements such as "[I] Concentrated hard on doing well" or "[I] Gave up the attempt to do well" elucidate participants motivations and thoughts when completing a task in order to understand whether the participant actively engaged with and tried to solve/succeed in the task, or whether they were distracted by their emotions, or tried to avoid thinking too much about the task. Participants rate their level of agreement on a five-point scale with questions for each scale interleaved. Each subscale comprises of

seven questions, with higher total scores reflecting higher (*x*)-focused coping. A study by Wilks, Geiger, Boyd and Chaney (2015) reported strong Cronbach's Alphas across each subscale (.77 to .85) as well as good split-half reliabilities (.67 to .82).

3.4.3 Stress Induction

Selected for its rapid administration (~3 mins), the experiments used the Socially Evaluative Cold Pressor Task (SECPT) to elicit stress. The Cold Pressor Task itself was administered using a refrigerating bath circulator (Jeio Tech Lab Companion – RW-0525G), with sterilised water maintained at a constant temperature of 3°C, ± 2°C for the cold water (stress) condition, or 37°C, ± 2°C for the warm water (control) condition. Participants were instructed to keep their non-dominant hand immersed under water for a period of three minutes, unless the procedure became painful, in which case they should remove their hand immediately. Towels were provided to dry and warm their hands after the task.

For the social evaluation portion of the task, stress participants were informed that whilst they completed the CPT, they would be filmed and their facial expressions recorded for comparison against other participants. Although no filming took place, a Sony HDR-PJ220 digital camcorder was positioned on a SLIK tripod at eye level, approximately 80cm in front of the participant, and the experimenter simulated pressing the record button, before turning and watching the participant intently. For control participants, no camcorder was present and the experimenter stepped outside of the laboratory (they were able to check compliance by viewing through a spyhole).

3.4.4 Saliva Sampling and Biochemical Analysis

As the preferred method of collection for psychophysiological research (Kudielka, Gierens, Hellhammer, Wüst, & Schlotz, 2012), saliva samples were collected using synthetic salivettes (Sarstedt) to measure both salivary α-Amylase (sAA) and salivary

Cortisol (sCortisol) level. Both sAA and sCortisol have been shown to reflect a physiological response to stress, indicating increased SNS and HPA-Axis activity, respectively. As per the manufacturer's instructions, and under supervision of the principal investigator, participants held the salivette in their mouth, chewing occasionally, for a period of two minutes before returning it to its plastic container. Samples were immediately frozen and stored at approximately – 25°C. Analysis was performed at the University of Trier (TrierLab, Germany) using the DELFIA assay (time-resolved fluorescence immunoassay) described in Dressendörfer, Kirschbaum, Rohde, Stahl and Strasburger (1992). Samples were analysed in duplicate, with the mean reported. Coefficient of Variation (CV) was calculated, and samples reanalysed if CV exceeded 15% (25% if Cortisol value was lower that 2nmol/l).

3.4.5 Procedure

For the experiments described in Chapters Four, Five and Six, each experimental procedure followed the same fundamental structure. Participants were invited to attend a single experimental session lasting three hours. Experiment One was conducted both during the morning and the afternoon, with sessions commencing at either 0930 or 13:00. These times were selected in order to account for both the diurnal cycle of Cortisol (Dickerson & Kemeny, 2004) and Alpha Amylase (Harmon, Towe-Goodman, Fortunato, & Granger, 2008), as well as the expected differences in ANT-R performance between morning and afternoon (Knight & Mather, 2013).

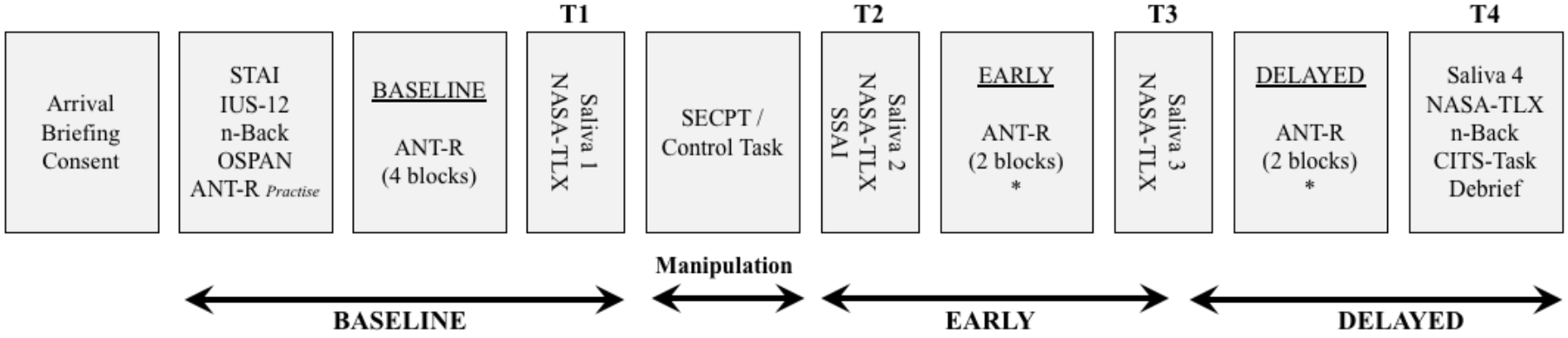
Participants were asked not to eat or drink anything except water for 60 minutes prior to attending the session in order to provide uncontaminated saliva samples and to control for potential confounds to the biomarkers caused by glucose/carbohydrate/caffeine ingestion (Nehlig, Daval, & Debry, 1992). Participants were made aware of the exclusion criteria in advance and requested not to book an experimental session if they did not satisfy all criteria. Upon arrival, adherence to the criteria was checked by the experimenter,

before providing a comprehensive written and verbal brief. Participants gave written consent and were reminded of their right to withdraw, up to the point of completion. Withdrawal was not possible post-completion as data was anonymised using unique identifiers. Participants were instructed how to collect saliva using the salivette, placing it to the side of their mouth close to the parotid gland, for two minutes in order to saturate the swab (Harmon et al., 2008).

Following the briefing, participants initiated the experiment by completing the Baseline portion of the session, which included the cognitive, workload and physiological measures (see Figure 3.2). Participants then completed either the SECPT or the equivalent warm water control task, before immediately completing the 'Early', post-stressor measures, which included physiological, cognitive and workload measures. Following this, participants engaged in the delayed, or 'Delayed' post-stressor portion, completing their final cognitive, physiological and workload measures before being debriefed, and concluding the session.

The procedure was repeated in Experiments Two and Three with the following alterations: 1) Experiment Two was performed exclusively in the afternoon with sessions commencing at 12:50 or 13:00. 2) Experiment Three was exclusively performed in the morning with sessions commencing at 09:15 or 09:30. 3) In both Experiments Two and Three, following the SECPT/control task, participants completed only one ANT-R (two blocks), with the period instead filled with 15-minutes of 'relaxation' where participants were encouraged to relax, or engage in some light reading in the laboratory. Determination of whether the ANT-R (two blocks) was performed in the Early, or Delayed period was randomly counterbalanced between participants, within each experiment.

Figure 3.2 Runtime order



* In Experiments Two and Three, each participant completed only one post-manipulation run of the ANT-R, instead completing a 15 minute 'relaxation' task in the remaining period. The order of the ANT-R/relaxation task was counterbalanced across participants for each experiment.

Runtime order for the three empirical studies. Each experiment was split into three 'tranches': a baseline tranche collected trait information and baseline scores for cognitive and physiological measures, before 'early' and 'delayed' tranches collected similar measures either immediately following the manipulation, or in a delayed period approximately 20 minutes later.

4 Experiment One

4.1 Chapter Overview

Following the pilot study (Chapter Two), I now introduce the first empirical experiment to employ a similar design. Using the Attentional Network Test-Revised (ANT-R), baseline attentional performance (efficiency) was recorded before conducting a comparison to performance following either the SECPT or a comparable control. The comparison was made at two specific points post-stressor, roughly aligned with known physiological responses to stress exposure. These were immediately (or "early" – 0-15 mins), to reflect the SNS response, and in a delayed period (20-35 mins) reflecting the HPA-Axis' response. To complete the ANT-R within these constrained periods, only one ANT-R (four blocks) was used post-stress, with split halves (two blocks) used to examine performance in each discrete period. Stress state was recorded using self-reported (anxiety and workload) and physiological (salivary Alpha Amylase and Cortisol) measures. Additional factors including coping, gender and working memory were also assessed.

4.2 Introduction

Experiencing acute stress is of significant interest within the psychological literature due to its potential to have a marked effect upon a person's health and wellbeing (Schneiderman, Ironson, & Siegel, 2005). Decades of investigation has produced results that offer little clarity regarding the effect stress can have on different aspects of cognition, ranging from memory (Schwabe, Joëls, Roozendaal, Wolf, & Oitzl, 2012) and decision-making (Pabst, Schoofs, Pawlikowski, Brand, & Wolf, 2013) to working memory (WM) (Olver et al., 2015) and attentional performance (Sänger et al., 2014).

Defined as the ability to "select the most relevant stimuli in the physical world for processing, while filtering out less relevant information" (Katsuki & Constantinidis, 2014,

p. 509), attention has been extensively examined following stress, with inconsistent conclusions. This is true across the various aspects of attention including selective and sustained attention (or vigilance) (Chajut & Algom, 2003; Helton et al., 2009; Henckens et al., 2012; Roelofs et al., 2007; Vinski & Watter, 2013) and divided attention (Kaess et al., 2016; Matthews et al., 1996; Petrac et al., 2009). Additionally, inconsistencies are reported across different modalities, including auditory (Elling et al., 2011) and visual attention (Elling et al., 2012; Shahsavarani, Ashayeri, Lotfian, & Sattari, 2013).

4.2.1 Measuring Attention

One potential explanation is the array of tasks available to researchers when measuring specific types of attention. For instance, to assess sustained attention researchers have employed the Psychomotor Vigilance Task (PVT - Dinges, 2004; Shia et al., 2015), the Sustained Attention to Response Task (SART - Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Alomari, Fernandez, Banks, Acosta, & Tartar, 2015), the Paced Auditory Serial Addition Task (PASAT - Gronwall, 1977; Delawalla, Newcomer, & Rodebaugh, 2010; Tarazona et al., 2013), Visual Continuous Performance tasks (Petrac et al., 2009) or created their own bespoke tasks (Szalma, 2011). Although all are defined as a measure of sustained attention, the manner by which they operationalise that is varied. It is conceivable that such variation could explain the conflicting results within the literature, as described in Chapter One – Introduction. Instead, investigation of attentional efficiency might allow clarification of the impact of stress on attentional performance.

"Attentional Network Theory", advocated by Posner and Petersen (1990; later Petersen & Posner, 2012), proposed three attentional networks; alerting, orienting and executive control (see Chapter One). These fundamental networks are engaged both individually and cooperatively to deploy attention effectively. However, many of the tasks exploring sustained attention operate by exploiting different networks (e.g. the PVT relies predominantly on the alerting network as its measure of sustained attention as participants

respond to infrequent signals, whereas the SART relies more on executive control as participants inhibit a routine response when presented with a target). A task that measures performance across the networks, such as the Attentional Network Test-Revised (ANT-R - Fan et al., 2009), may elucidate how exposure to acute stress influences performance on the previously discussed tasks. No existing work has considered ANT-R performance within an acutely stressed population.

4.2.2 The ANT-R

Fan et al. (2009) designed the ANT-R to measure performance efficiencies of each of the three attentional networks, as well as to identify interactions between the networks following a criticism of the original ANT (Corbetta & Shulman, 2002; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Macleod et al., 2010). The original combined a Posner cuing paradigm (Posner, 1980) with an Eriksen flanker task (Eriksen & Eriksen, 1974) whilst the revised version also incorporates a location effect (Simon & Wolf, 1963) and various Cue to Target Onset Asynchronies (CTOAs).

In the ANT-R, participants indicate the direction of a central arrow, that is flanked by a series of congruent or incongruent arrows, following a cue (no cue, spatially valid/invalid cue and double cue). Accuracy and response times (RT) are the output measures, calculated as difference scores from various combinations of the cue, location and flanker manipulations. For instance, an efficiency score for the alerting network (in accuracy or RT) can be calculated as the difference between 'no cue' trials and 'double cue' trials, where the inclusion of a double cue (that lacks spatial information) presents an alerting benefit by indicating an imminent trial (for more details see Fan et al., 2009, for complete set of output measure equations, see section 4.4.3.1). Previous research has shown that individual differences can affect attentional network performance, including age (Jennings et al., 2007), gender (Liu et al., 2013), obesity (Beutel et al. 2006, as cited in Macleod et al., 2010), dyslexia (Bednarek et al., 2004) and working memory. However,

the task has been well validated in both healthy and clinical populations (Antón et al., 2014; Keehn et al., 2010; Kubesch et al., 2009; Pacheco-Unguetti et al., 2011) and offers an opportunity to examine attentional efficiency in an acute stress paradigm.

4.2.3 The Time-course of Stress Physiology

A further reason for the contradictory findings in the literature might be the lack of consistency as to when post-stress cognitive change is measured in different studies. Previous work has examined change in the immediate aftermath (Elling et al., 2011), delayed periods (5-60 minutes) (Plessow et al., 2011; Sänger et al., 2014), as well as up to 24 hours later (Bolger et al., 1989). However, there often appears to be a lack of principled reasons for why these particular testing periods have been selected. Instead, this study proposes to measure changes to attentional performance in periods roughly aligned with known physiological reactions to acute stress.

It has already been established that when experiencing a novel, acutely stressful encounter, two physiological pathways are engaged in an attempt to cope and ultimately return the body to a homeostatic state; the Sympathetic Nervous System (SNS - Lambert & Lambert, 2011); and the Hypothalamic-Pituitary-Adrenal (HPA) Axis – part of the neuroendocrine system (Dickerson & Kemeny, 2004; D. B. Miller & Callaghan, 2002). Increased production of adrenaline (SNS) and Cortisol (HPA-Axis), alongside elevated heart rate and glucose supply to the muscles, allows the body to deal with threat and can impact cognition (Robinson et al., 2013). However, these two physiological pathways follow distinct time-courses following stress exposure; SNS activation is immediate and short-lived with activity peaking within 10-15 minutes before quickly disappearing. Alternatively, HPA-Axis activation is immediate yet appears delayed, building to a peak occurring approximately 20-30 minutes post-stress (Kirschbaum & Hellhammer, 1994), with research demonstrating that effects to cognition can persist for up to two hours after exposure to stress (Tops et al., 2003). The delayed HPA-Axis response in particular has

been shown to act independently of a person's subjective experience, such that people may feel they have returned to homeostasis following stress, but are still undergoing a significant physiological reaction (Robinson et al., 2008; Schommer et al., 2003).

Existing research appears to take a limited account of these physiological responses and their relationship to altered cognitive function. Instead, the majority of studies tend to 1) focus on a single physiological pathway (Renner & Beversdorf, 2010; Roelofs et al., 2007); 2) take cognitive measures at a different time to the physiological measure they are collecting (Robinson et al., 2008; Schoofs et al., 2009), or 3) collect a single cognitive measure across an extended SNS and HPA-Axis profile, often concluding a global effect of stress on that cognitive function (Scholz et al., 2009; Schoofs et al., 2008).

In order to understand the effects of acute stress on attention more precisely, it could be advantageous to measure performance whilst each physiological pathway is maximally engaged. Studies exploring working memory (Robinson et al., 2013) and emotional processing (Alomari et al., 2015) have followed such a design, whilst Elling et al. (2011) applied this specific approach with regards to auditory attention. However, an investigation examining visual attention appears lacking. One study by Olver et al. (2015) did come close, measuring both SNS and HPA-Axis activity in an immediate post-stress phase, and a later recovery phase (approximately 70-minutes post-stress). The authors noted no significant Cortisol changes immediately after exposure, instead reporting a significant decrease to Cortisol between stress exposure and recovery. However, the 70-minute delay probably missed the Cortisol peak (ordinarily 20-45 minutes post-stress; Kirschbaum & Hellhammer, 1994) and therefore the ability to associate any cognitive change with the physiological reaction. The present study intends to apply such an approach to examine different aspects of visual attention, using the ANT-R, during discrete phases immediately following exposure (SNS reactivity period) and in a delayed period (HPA-Axis reactivity period) when physiological responses are likely to be near their peak.

4.2.3.1 Individual Physiology

Furthermore, the present study will also examine whether an individuals' response to acute stress influences the direction or magnitude of any change to attentional performance. Individual factors such as age and gender are often examined for their effect on performance, whereas individual responses to stress (such as appraisal, state anxiety and physiological reactions) are mainly used to verify that stress has been experienced. Instead, I intend to will examine whether an individuals' response to acute stress exposure conveys any direct influence on changes to attention.

4.2.4 Selected Stressor

A final issue to consider is the variety of different stressors utilised throughout the literature. McGrath (1976) described stress as an interaction of three elements; the perceived demand of an event, the individuals perceived ability to cope, and the importance placed upon such coping ability. Although naturalistic stressors fulfil these criteria and offer representative experiences of stress, controlled measurement is inherently more difficult. Thus, numerous laboratory-based stressors have been developed that are designed to be both unpredictable and uncontrollable, yet elicit reliable experiences of stress such as physiological reactivity, workload, mood change and coping. The most popular of these are the Trier Social Stress Test (TSST - Kirschbaum, Pirke, & Hellhammer, 1993) and the Cold Pressor Task (CPT - Hines, 1937 as cited in Schwabe et al., 2008) which endure due to their easy administration and their extensive validation, with the TSST shown to elicit the strongest response (Skoluda et al., 2015). However, given the current aims of the research – to measure performance change in discrete post-stress periods related to physiological activation – the TSST is unsuitable due to its lengthened administration. Instead the study will employ a modified CPT task, the SECPT, that has been shown to elicit a strong physiological response (more so than the CPT) whilst also permitting rapid administration (Schwabe et al., 2008).

4.2.5 Hypotheses

The purpose of the present study is to investigate the impact of acute stress exposure on three hypothesised attentional networks; alerting, orienting and executive control.

Firstly, it is hypothesised that exposure to the SECPT will result in participants experiencing greater levels of stress, compared to participants who experience the comparable control task. This will be demonstrated by significantly higher state anxiety, workload, and coping, specifically task-focused coping. Participants in the stress group are also expected to demonstrate significantly lower performance satisfaction.

Furthermore, it is anticipated that exposure to the SECPT will produce a typical physiological response to the stressor, reflecting activation of both the SNS and the HPA-Axis. SNS activation will be demonstrated by increased sAA levels in the period immediately following exposure to the SECPT (Time-point 2). HPA-Axis activation will be demonstrated by increased Cortisol levels in the delayed period following the SECPT (Time-point 3).

Existing work has neglected to examine attentional networks under stress, however cursory predictions are made by examining the previous literature regarding the key components of each network.

Numerous studies have examined the effects of stress on vigilance, a crucial component of the alerting network, with previous work demonstrating the "vigilance decrement", where alertness reduces with increasing "time-on-task"; usually around 15 minutes (Hancock, 1986; N. H. Mackworth, 1948; Verster & Roth, 2013). However, participants are not expected to experience any significant "vigilance decrement" in the present study as each post-stress run of the ANT-R will last a maximum of 15 minutes and include a short break. Therefore, performance would not be expected to deteriorate. Instead, other studies have stated that under conditions of acute stress, vigilant attention is often improved by way of shortened RTs (Helton et al., 2009; Weymar et al., 2012). There

have also been reports of enhanced vigilance following both immediate neurophysiological arousal (Olofsson, Nordin, Sequeira, & Polich, 2008; van Marle, Hermans, Qin, & Fernandez, 2009) and latter endocrine arousal (Cortisol) (Akinola & Mendes, 2012; Roelofs et al., 2007; Veer et al., 2011). This suggests that following exposure to an acute stressor, performance efficiency of the alerting network will be enhanced during both the immediate and delayed periods. However, this enhanced alerting benefit is only anticipated to impact RT as the presence of a temporal cue should not influence target accuracy. Therefore, no change to accuracy-based alerting is predicted.

Very little existing work has explored the impact of stress on cue validity effects, although related work exploring how negative emotional states, such as increased physiological activity, low mood or anxiety level is common (Lang, Davis, & Öhman, 2000; Mogg, Holmes, Garner, & Bradley, 2008; Weymar et al., 2012). Results often reflect an emotional bias, whereby these negative states produce improved response times or increased perseverance to negative cues (occasionally positive cues) but with no discernible change to neutral cues, which act as a baseline. The ANT-R uses neutral cues, therefore affective state would not be anticipated to impact on validity performance. However, in the present study it is predicted that exposure to stress will result in hypervigilance (see above). If correct, there is unlikely to be any discernible difference between groups on valid trials as both sets of participants are cued toward the target. However, participants exposed to stress may demonstrate reduced RTs on invalidly cued trials as their hypervigilant state permits them to reorient their attention to the target's location more quickly than controls. Therefore, stress participants are predicted to experience a reduced validity effect (RT), relative to their control counterparts. As cue location is unrelated to target direction, no effect is anticipated for accuracy[4].

[4] Any accuracy effect would need to be further examined in the context of a cue congruency interaction. For instance, is the location of the cue (e.g. right) the same as the direction of the target (e.g. right facing). Hypervigilance may explain this effect on accuracy but there have not

Although work has shown that exposure to stress can increase activation in neural networks and areas related to attentional reorienting (Hermans et al., 2011), studies reporting tangible change to orienting performance are few. Several studies have reported poorer orienting following exposure to stress, however these studies often lack the ability to separate the effects as either SNS or HPA-Axis reactions (Olver et al., 2015; Vedhara et al., 2000). One study by Sänger et al. (2014), did find that stressed participants demonstrated a greater level of distractibility when attention was measured 25-40 minutes post-stressor, which would imply orienting should be poorer during the delayed period, resulting in an enlarged orienting effect (RT). However, it is predicted that exposure to stress will instead result in hypervigilance. Consequently, performance on double cue trials should be improved (relative to controls) as participants orient to the target more quickly than their control counterparts. This will result in a reduced orienting effect for participants in the stress group, compared to controls. Performance is not expected to be manifestly different for accuracy (see Footnote 4).

Easterbrook (1959) suggested that negative affect initiates a narrowing of attention. Chajut and Algom (2003) offered further data supporting for this view when they reported that selectivity of attention improved under conditions of stress (also see van Steenbergen, Band, & Hommel, 2011). If true, stressed participants should process incongruent and congruent (flanker) trials equally fast and accurately, as incongruence (distractors) fails to impede performance. However, control participants should still be negatively affected by the incongruent flankers. Therefore, if attention is narrowed by stress, the flanker effect will be reduced due to poorer performance on incongruent trials.

In contrast, various reports have shown that decision making, inhibition and working memory, all key components of effective executive control, have shown detrimental effects in the delayed aftermath of a stressor (Alomari et al., 2015; Elling et al.,

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been any previous reports of cue congruency effects in the ANT-R, thus changes to accuracy are not predicted.

2011; Robinson et al., 2013; Schoofs et al., 2008, 2009). If exposure to stress does negatively impact decision making and inhibition, participants would likely be unaffected on congruent flanker trials. However, they would be less able to inhibit incongruent flankers, resulting in an enlarged flanker effect for stress participants compared to controls (both accuracy and RT).

Finally, it is hypothesised that higher levels of physiological biomarkers indicating stress state (salivary Alpha Amylase and Cortisol) will be positively associated with the above stated cognitive changes, indicating that the strength of response to the stressor influences the strength/direction of the cognitive change.

4.3 Method

4.3.1 Participants

Sixty-five healthy men and women aged 18 to 44 ($\bar{x}$ *age* = 20.89 yrs, *SD* = 3.91 yrs) participated and were randomly assigned to a control group (Warm Pressor Task: *n* = 32, [17 female], $\bar{x}$ age = 21.63 yrs, SD = 5.15 yrs), or a stress manipulation group (SECPT: *n* = 33, [18 female], $\bar{x}$ age = 20.18 yrs, SD = 1.98 yrs) using a randomised block design. Participants were students or staff at the University of Southampton, recruited via the university's online research portal and on-campus advertisements. Participants provided written informed consent and upon termination of their session were compensated with a maximum of £18, or credits towards partial fulfilment of their course requirements.

4.3.1.1 Exclusions

Exclusionary criteria were applied as described in Chapter Three - Methodology. Within this experiment, all participants achieved the minimum level of accuracy required at baseline and therefore were included in the initial data analyses (*n* = 65).

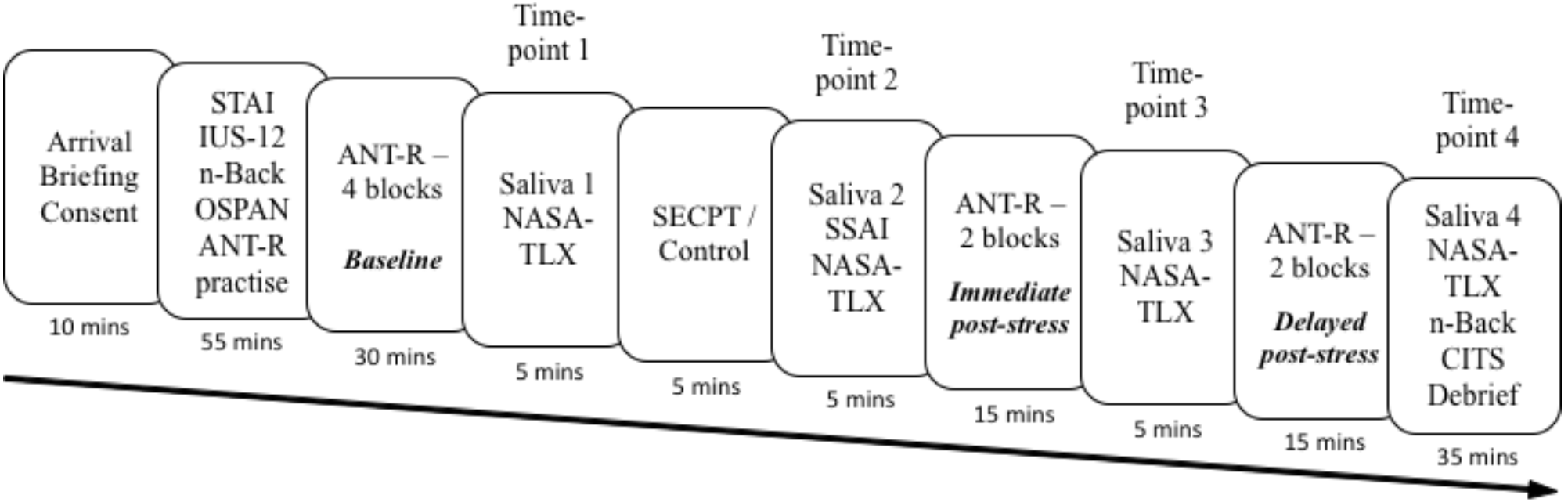
When exploring the physiological response (ANOVAs) and influence of physiology on ANT-R performance (regressions), four participants were excluded as a

result of their basal physiological data exceeding 2 SDs from the mean. A further three participants were also excluded as they had missing or incomplete saliva data (n = 58).

4.3.2 Apparatus and Procedure

Apparatus and the procedure are detailed in Chapter There. Experimental sessions commenced at 09:30 or 13:30 and the order of tasks can be seen in the following schematic (Figure 4.1).

Figure 4.1 Runtime order for Experiment One



Schematic detailing the order of tasks that participants experienced during Experiment One. (STAI = Spielberger Trait Anxiety Index; IUS-12 = Intolerance of Uncertainty; n-Back working memory (WM) task; OSPAN = Operational Span WM task; NASA-TLX = workload task; SSAI = Spielberger State Anxiety Index; CITS = Coping Inventory for Task Stress – Situational).

4.4 Results

4.4.1 Analysis design

In all analyses, Greenhouse-Geisser corrected degrees of freedom were used where the assumption of sphericity was violated. Effect sizes reported include partial η^2 (ANOVA), Cohens *d* (t-tests) and Glass's *Delta* (Δ – t-tests where SDs between groups exhibited large variation). Analyses were conducted in three stages:

1) Group differences and stress manipulation check:

A series of independent samples t-tests examined potential differences between participants in the stress and control groups.

To check the efficacy of the stress manipulation, a series of 2 (Condition: Stress vs Control) x 4 (Time-point: T1 to T4) x 2 (Time of Day: AM vs PM) repeated measures ANOVAs were performed on all self-report measures (modified NASA-TLX). Condition and Time of Day were the between-subjects' factors, and Time-point was the within-subjects' factors.

Similar ANOVAs, with an additional between subjects' factor of Sex* (Male vs Female) examined physiological markers of stress. Of interest was an interaction between Condition and Time-point, which would reflect a group difference following exposure to the stressor. However, interactions with Time of Day were to be assessed to account for the diurnal cycles of Alpha Amylase and Cortisol (also, Cortisol Awakening Response – Edwards, Evans, Hucklebridge, & Clow, 2001), whilst interactions with Sex were examined due to known biological differences between males and females following exposure to a stressful experience (van Stegeren et al., 2008). Planned comparisons using ANOVAs and independent samples t-tests were performed to elucidate any significant differences.

* Sex is employed where the analysis concerns physiology, for all non-biological analysis, Gender is used instead.

2) ANT-R performance:

A series of paired samples t-tests were performed on the raw baseline ANT-R data to check whether the ANT-R was producing the expected effects (e.g. alerting effect: significant difference present between 'No Cue' and 'Double cue' performance). Global accuracy and RT were then calculated to 1) understand evolution of performance over repeated iterations, and 2) confirm the task was equally as reliable as that used in the pilot study (Chapter Two).

A series of 2 (Condition: Stress vs Control) x 3 (Tranche: Baseline / Early / Delayed) x 2 (Time of Day: AM vs PM) x 2 (Gender: Male vs Female) repeated measures ANOVAs, with Condition, Time of Day and Gender as the between-subjects' factors, and Tranche as the within-subjects factor, were then performed to examine the influence of Stress, Time of Day and Gender on ANT-R performance. Primary interest was a Condition and Tranche interaction that would indicate exposure to stress affected attentional performance. Additionally, a 3-way (or 4-way) interaction between Condition, Tranche and either Time of Day / Gender, would suggest that the influence of stress was dependent upon participant gender and/or time of day of measurement. Although the focus of the experiment was limited to only four of the measures within the ANT-R, alpha-values still required adjustment. Given the inter-dependencies of the four effects which encompass the alerting, orienting and executive control networks, a correction by three was deemed conservative, yet sufficient to account for the interaction between those attentional networks. Alpha–values were therefore adjusted from 0.05 to 0.017. A full report of the analyses outputs is available in Appendix C).

3) Influence of physiology on ANT-R performance:

To understand any direct influence of physiological reactivity to stress on attentional performance, a multiple regression was performed on each of the four ANT-R measures, for both accuracy and RT, at baseline, early and delayed periods. Predictor variables entered into the regressions can be viewed in detail in section 4.4.4.2.

4.4.2 Groups – Stress vs Controls

Independent samples t-tests demonstrated no significant group differences between the control participants and stress participants in gender, birth control (use or type) age, handedness, trait anxiety, intolerance of uncertainty, nor n-Back or OSPAN working memory. Similarly, an equal share of participants was tested in both the morning and afternoon sessions (all p's > .146).

As expected, participants did differ significantly by the amount of time they spent performing the SECPT/control task, with control participants spending significantly longer time with their arm immersed in water than stress participants (control $\bar{x}$ = *180 seconds*, stress $\bar{x}$ = *151.64 seconds*) ($t(32) = 2.98$, $p = .006$, *Glass's* $\Delta = 27.36$).

4.4.2.1 Self-report measures

An independent samples t-test showed a significant difference of state anxiety (SSAI) immediately following the manipulation across groups ($t(63) = -6.62$, $p < .001$, $d = 1.64$). In accordance with the hypothesis, participants who experienced the SECPT reported significantly higher state anxiety immediately following the task than those who completed the equivalent warm water control task.

A series of 2 (Condition: Stress vs Control) x 4 (Time-point: T1 to T4) repeated measures ANOVAs were performed on each of the seven NASA-TLX (modified) measures, with an interaction between Condition and Time-point of primary interest. Significant interaction effects were observed for all seven measures (all F's > 4.10, all p's < .019, partial η^2's > .06). Planned comparisons using independent samples t-tests revealed a significant difference at T2 (i.e. immediately following the stressor) for each measure (all p's <.001, all *Glass's* Δ's > 1.80). Further, all significant differences appeared in the hypothesised directions, with performance ratings lower amongst stress participants and all other workload measures higher (T2 means are shown in Table 4.1).

For every measure, differences at other time-points did not reach significance (all *p*'s >.148). For raw data (including at other time-points) see Appendix C.

Table 4.1 *Mean (SD) ratings by participants on Spielberger State Anxiety Index (SSAI – scores 0-80) and NASA-Task Load Index (scores 0-100) immediately following stress exposure or control (T2).*

		SSAI	Mental	Physical	Temporal
Condition	*n*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	32	31.41 *(8.25)*	5.59 *(5.50)*	17.88 *(15.26)*	8.41 *(8.54)*
Stress	33	45.45 *(8.85)*	46.27 *(30.03)*	76.12 *(22.69)*	23.79 *(20.59)*

		Performance	Effort	Frustration	Stress
Condition		Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	32	91.78 *(10.47)*	9.59 *(11.94)*	7.78 *(10.33)*	7.41 *(8.20)*
Stress	33	62.61 *(33.27)*	77.64 *(18.11)*	46.52 *(28.59)*	64.64 *(24.73)*

A series of independent samples t-tests examined participants coping behaviour, and demonstrated no difference between groups in overall coping score, or individual coping type (task- / emotion- / avoidance-focused) (all *t*'s < .50, all *p*'s > .618, all *d*'s < .12). Contrary to our prediction, stress participants did not engage in significantly greater levels of coping than their control counterparts.

4.4.2.2 Alpha Amylase

For sAA reactivity, there was a main effect of Time ($F(2.61,130.56) = 4.44$, $p = .008$, partial $\eta^2 = .08$), with post hoc paired samples t-tests indicating that sAA level increased from T1 to T2 ($t(57) = -3.01$, $p = .004$, $d = .22$) and T3 ($t(57) = -2.41$, $p = .019$, $d = .17$). This suggests that regardless of Condition, sAA increased from baseline following the manipulation (other differences were not significant – all *p*'s > .070 – see Figure 4.2). Interestingly, there was no interaction of Time and Condition ($F(2.61,130.56) = .18$, $p = .890$, partial $\eta^2 = .00$). However, planned paired samples t-tests examining Condition independently showed that whilst control participants only experienced a significant increase from T1 to T2 ($t(27) = -2.15$, $p = .041$, $d = .29$), stress participants showed

significant increases from T1 to T2 ($t(29) = -2.1$, $p = .045$, $d = .17$) and T3 ($t(29) = -2.07$, $p = .047$, $d = .17$) as well as a non-significant increase at T4 ($t(29) = -1.89$, $p = .069$, $d = .14$). No other differences reached significance (all p's > .109). Contrary to predictions, this indicates that in addition to the stress group participants, control participants also exhibited increased sAA levels immediately following their control task. However, this increase did not persist for the duration of the experiment as it did for participants in the stress group following the SECPT.

Of additional interest, there was a significant interaction of Time-point and Sex ($F(2.61, 130.56) = 3.43$, $p = .024$, partial $\eta^2 = .06$). Post hoc paired samples t-tests indicated that amongst males, sAA significantly increased from T1 to T2 ($t(24) = -2.55$, $p = .017$), and decreased significantly from T2 to T3 ($t(24) = 2.59$, $p = .016$) and T4 ($t(24) = 2.37$, $p = .026$). Although this matched the anticipated sAA profile post-stress, the increase was observed amongst all males and was not limited to only those who experienced the SECPT. Differences between other time-points were non-significant (all p's > .475). Similarly, amongst female participants sAA levels also significantly increased. However, the difference was from T1 to T3 ($t(32) = -2.79$, $p = .009$. There was no other significant difference between time-points (all p's > .068). The results indicate that both males and females, regardless of their assigned condition exhibited an increase in sAA, even without exposure to the SECPT. However, whilst males sAA levels peaked at T2, female levels peaked at T3, approximately 15 minutes later. There were no other significant interactions observed in the ANOVA (all other p's > .213).

Figure 4.2 Salivary Alpha Amylase values at four time-points (stress and controls).

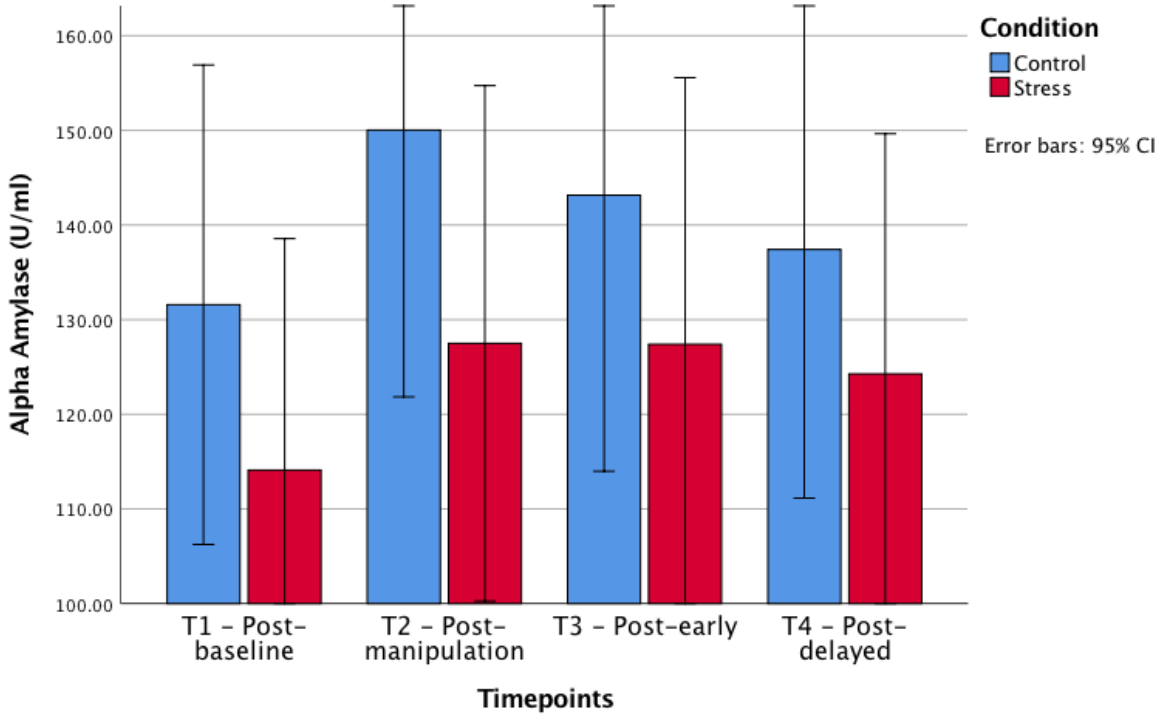


Figure 4.2. Graph demonstrates both control and stress participants experienced elevated sAA at T2. For controls, sAA then reduced toward baseline levels. However, stress participants sAA levels remained high.

4.4.2.3 Cortisol

For Cortisol reactivity, there was a significant main effect of Time ($F(1.34,67.04) = 10.97$, $p < .001$, partial $\eta^2 = .18$) and a significant interaction effect of Time and Condition ($F(1.34,67.04) = 18.48$, $p < .001$, partial $\eta^2 = .27$). Planned paired samples t-tests were performed to examine each Condition independently. Control participants demonstrated significant decreases in Cortisol from T1 to T3 ($t(27) = 3.92$, $p = .001$, $d = .35$) and T4 ($t(27) = 4.81$, $p < .001$. $d = .55$). There was no difference between T1 and T2 ($p = .222$). This demonstrates that controls participants Cortisol levels significantly reduced during the latter portion of the experiment. However, as expected participants in the stress group demonstrated a significant increase from T1 to T3 ($t(29) = -5.17$, $p < .001$, $d = 1.29$) and T4 ($t(29) = -3.37$, $p = .002$, $d = .87$). Again, there was no difference between T1 and T2 ($p = .862$). Participants who experienced the SECPT displayed the hypothesised elevation in Cortisol approximately 15 minutes post-stressor, and Cortisol level remained significantly high for the remainder of the experiment. (see Figure 4.3).

In addition, a three-way interaction of Time, Condition and Gender approached significance ($F(1.34,67.04) = 3.47$, $p = .055$, partial $\eta^2 = .07$). Post-hoc ANOVAs examining Gender individually demonstrated significant Time and Condition interactions for both males ($F(2.19,45.99) = 13.28$, $p < .001$, partial $\eta^2 = .39$) and females ($F(1.26,36.60) = 13.55$, $p < .001$, partial $\eta^2 = .32$). Paired samples t-tests demonstrated that for males, participants in the stress condition experienced significantly higher Cortisol levels than control participants at T3 ($t(16.89) = -3.61$, $p = .002$, $d = 1.42$) in line with predictions, and at T4 ($t(18.89) = -2.36$, $p = .029$, $d = .93$). There was no significant difference at T1 or T2 (all p's > .355). Similarly, female participants in the stress condition also experienced significantly higher Cortisol levels than controls at T3 ($t(17.66) = -6.27$, $p < .001$, $d = 2.15$) and at T4 ($t(17) = -5.27$, $p < .001$, $d = 1.81$). Differences at T1 and T2 did not reach significance (all p's > .072). The three-way interaction appears to result from females experiencing a relatively stronger effect of stress exposure compared to males. However, both experienced the hypothesised peak in Cortisol at T3, followed by a small reduction at T4 indicating recovery had commenced (for means see Table 4.2).

Figure 4.3 Salivary Cortisol values at four time-points.

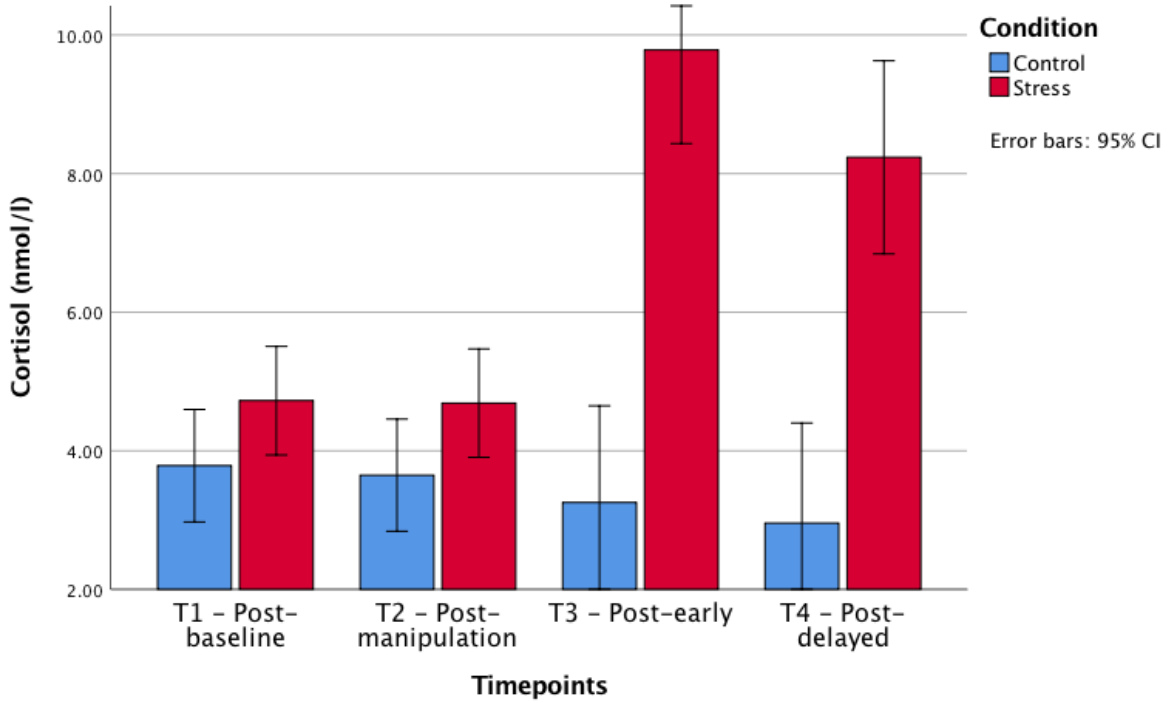


Figure 4.3. Graph demonstrates control Cortisol values steadily decreased over the duration of the study. However, stress participants exhibited a typical HPA-Axis response, as Cortisol peaked approximately 20-minutes after the stressor (T3).

Table 4.2 *Mean (SD) values of salivary Alpha Amylase (sAA – U/ml) and salivary Cortisol (nmol/l) by participants at four time-points.*

			Alpha Amylase (U/ml)*	Cortisol (nmol/l)^
	Condition	*n*	Mean *(SD)*	Mean *(SD)*
Time-point 1	Control	28	131.58 *(59.63)*	3.79 *(1.53)*
	Stress	30	114.10 *(73.03)*	4.72 *(2.59)*
Time-point 2	Control	28	150.03 *(66.28)*	3.65 *(1.54)*
	Stress	30	127.49 *(81.30)*	4.69 *(2.57)*
Time-point 3	Control	28	143.16 *(68.22)*	3.25 *(1.50)*
	Stress	30	127.39 *(84.46)*	9.78 *(4.92)*
Time-point 4	Control	28	137.41 *(63.21)*	2.96 *(1.49)*
	Stress	30	124.27 *(74.63)*	8.23 *(5.10)*

* sAA - Units per millilitre ^ Cortisol - nanomoles per litre

4.4.3 ANT-R

4.4.3.1 Measures

The ANT-R measures were calculated using the equations defined in Fan et al. (2009). The present study was interested in four effects: alerting benefit, the validity effect, moving and engaging (hereafter termed the 'orienting effect' – as it was termed in the original ANT [Fan et al., 2002]) and the flanker effect.

Alerting Benefit:	$Acc_{No\ Cue} - Acc_{Double\ Cue}$	/	$RT_{No\ Cue} - RT_{Double\ Cue}$
Validity Effect:	$Acc_{Invalid\ Cue} - Acc_{Valid\ Cue}$	/	$RT_{Invalid\ Cue} - RT_{Valid\ Cue}$
Orienting Effect:	$Acc_{Double\ Cue} - Acc_{Valid\ Cue}$	/	$RT_{Double\ Cue} - RT_{Valid\ Cue}$
Flanker Effect:	$Acc_{Incongruent} - Acc_{Congruent}$	/	$RT_{Incongruent} - RT_{Congruent}$

4.4.3.2 Reliability check

For the post-manipulation portion of the study, a "split" run of the ANT-R was used with the two initial blocks capturing performance immediately following stress (early), and the final two blocks capturing performance in a later stage (delayed). This was feasible as the two final blocks repeat the trials of first two blocks in the same order. However, to validate the approach, split-half reliabilities were calculated across all cue and flanker types for all 65 participants using their baseline ANT-R data. Pearson correlations demonstrated that performance on all cue / flanker conditions in the first half of baseline ANT-R (two blocks) correlated significantly with their counterparts in the second half (all r's > .45, all *p*'s < .001). Additionally, Pearson's correlations were calculated across the three "tranches" (Baseline / Early / Delayed). Global accuracy, and global RT, were each significantly correlated across three tranches (all *r*'s > .842, all *p*'s < .001). This indicates that performance on the attention task was relatively consistent across the three iterations of the task and therefore offers good reliability (see Table 4.3). Furthermore, it suggests that the task was as reliable as the task used in the pilot study (Chapter Two – all *r*'s > .703, all *p*'s < .001).

Table 4.3 *Correlation matrix for global accuracy (a) and RT (b) across three time-points (baseline / early / delayed).*

(a)

		Global Accuracy	Global Accuracy	Global Accuracy
		Baseline	Early	Delayed
Global Accuracy	Pearsons *r*	1	.842*	.889*
Baseline	Sig. (2-tailed)	1	.000	.000
Global Accuracy	Pearsons *r*		1	.871*
Early	Sig. (2-tailed)		1	.000
Global Accuracy	Pearsons *r*			1
Delayed	Sig. (2-tailed)			1

(b)

		Global RT	Global RT	Global RT
		Baseline	Early	Late
Global RT	Pearsons *r*	1	.907*	.872*
Baseline	Sig. (2-tailed)	1	.000	.000
Global RT	Pearsons *r*		1	.955*
Early	Sig. (2-tailed)		1	.000
Global RT	Pearsons *r*			1
Delayed	Sig. (2-tailed)			1

* Correlation is significant at the 0.001 level

4.4.3.3 Effects Check

The ANT-R's use of difference scores relies on consistent differences in performance between cue / flanker types. Therefore, in order to validate that the ANT-R was initiating the attentional effects as expected (e.g. alerting benefit – double cue consistently more accurate/quicker than no cue), a series of paired samples t-tests were performed between cue type performance at baseline. For accuracy, differences between cue / flanker types used to calculate the validity effect ($t(64) = -6.25$, $p < .001$, $d = .60$), and flanker effect ($t(64) = -5.67$, $p < .001$, $d = .90$) were significant, and in the expected

direction. Although they did not reach significance, differences for alerting benefit (p = .053, d =.13) and orienting effect (p = .121, d = .14) were in the expected direction.

For RT, there were significant differences between cue / flanker types for each effect in the anticipated direction (all p's < .001, all d's > .60). The results suggest that for accuracy, the validity and flanker effects are the most reliable measures (compared to alerting and orienting) as performance was both consistently and significantly better for the expected cue / flanker types. Regarding RT, all measures were significant indicating high reliability. This would also suggest that RT offers the most robust measure when compared to accuracy for measuring attentional efficiency.

4.4.3.4 ANT-R Performance Data

4.4.3.4.1 Global Effects

Overall accuracy was calculated for each participant and analysed using a 2 (Condition: Stress vs Control) x 3 (ANT-R Tranche: baseline / early / delayed) x 2 (Time of Day: AM vs PM) x 2 (Gender: Male vs Female) repeated measures ANOVA. There was a significant main effect of Tranche (F(2,114) = 5, p = .008, partial η^2 = .08). Planned comparisons using paired samples t-tests indicated significant differences in accuracy between baseline and delayed performance (t(64) = 2.99, p = .004, d = .17), and early and delayed performance (t(64) = 3.230, p = .002, d = .22), but no difference between baseline and early accuracy (p = .702). The analyses indicate that accurate performance on the ANT-R was stable between baseline and early, but that performance dropped significantly in the delayed tranche, regardless of condition. There were no other significant effects (all p's > .400). See Table 4.4 for means and standard deviations.

For Response Time (RT) an identical 2 x 3 x 2 x 2 repeated measures ANOVA was performed. Again, there was a significant main effect of Tranche (F(1.57,89.38) =13.08, p < .001, partial η^2 = .19). Planned comparisons using paired samples t-tests demonstrated significant differences in RT between baseline and early performance (t(64) = 5.07, p <

.001, d = .27), baseline and delayed performance (t(64) = 2.52, p = .014, d = .16), and early and delayed performance (t(64) = -2.628, p = .011, d = .10). The analyses indicate that RT performance significantly improved from baseline to the early tranche, but slowed significantly in the delayed tranche.

There was also a significant three-way interaction of Tranche, Time of Day and Gender (F(1.57,89.38) = 3.44, p = .047, partial η^2 = .06). Post-hoc ANOVAs demonstrated that whilst females saw no effect of Time of Day on Tranche performance (p = .389), males did see a significant interaction (F(2,52) = 3.39, p = .041, partial η^2 = .12). Further paired samples t-tests demonstrated that males in the morning group experienced improved RTs at early (t(16) = 3.35, p = .004, d = .23), followed by a trend of slower RTs at delayed (t(16) = -2.28, p = .037, d = .17) consistent with the group behaviours reported above (baseline - delayed difference p = .636). However, males in the PM group experienced improved RT from baseline to both early (t(12) = 3.41, p = .005, d = .32) and delayed (t(12) = 3.41, p = .005, d = .34), with no difference between early and delayed (p = .635). No other effects were significant (all p's > .244). See Table 4.4 for means and standard deviations.

Table 4.4 *Mean (SD) values of global accuracy and RT performance across three tranches of the ANT-R.*

			Baseline	Early	Delayed
	Condition	*n*	Means *(SD)*	Means *(SD)*	Means *(SD)*
Accuracy *(%)*	Control	32	96.91 (3.91)	96.74 (3.20)	95.86 (4.06)
	Stress	33	96.11 (6.17)	96.53 (4.75)	95.35 (6.12)
	Total	65	96.50 (5.16)	96.63 (4.03)	95.60 (5.17)
RT *(ms)*	Control	32	572.86 (54.98)	553.05 (59.03)	561.38 (64.00)
	Stress	33	566.48 (78.43)	550.27 (68.81)	555.94 (77.98)
	Total	65	569.62 (67.46)	551.64 (63.70)	558.62 (70.94)

4.4.3.4.2 Alerting Benefit

In order to understand if exposure to Stress, Time of Day or Gender influenced alerting benefit, a 2 (Condition: Stress vs Control) x 3 Tranche (Baseline / Early / Delayed) x 2 (Time of Day: AM vs PM) x 2 (Gender: Male vs Female) repeated measures ANOVA was performed. Regarding accuracy, there was no significant interaction of Tranche and Condition ($F(1.54,88) = 1.33$, $p = .266$, partial $\eta^2 = .02$) indicating that exposure to stress did not influence alerting accuracy across the three time periods. However, there was a significant interaction Tranche and Time of Day ($F(1.54,88) = 4.37$, $p = .024$, partial $\eta^2 = .07$). Post-hoc paired samples t-tests revealed there were no significant differences between tranches during the morning (all p's > .137). However, for afternoon participants there was a difference between early and delayed that was significant ($t(32) = 2.15$, $p = .039$, $d = .54$), but other time-points did not reach significance (p's > .059). The result indicates that for both stress and control participants, the alerting benefit appeared to increase in magnitude between the early and delayed periods, but only when tested in the afternoon. There were no other significant effects in the ANOVA (all p's > .168).

An identical ANOVA was performed for RT, however no effects reached significance (all p's > .232).

4.4.3.4.3 Validity Effect

As above, an ANOVA was performed to examine the impact on the validity effect. Regarding accuracy, the interaction of Tranche and Condition failed to reach significance ($F(2,114) = .66$, $p = .520$, partial $\eta^2 = .01$). However, there was a main effect of Gender ($F(1,57) = 7.49$, $p = .008$, partial $\eta^2 = .12$) which reflected a larger validity effect in males overall, than females (Male: $\bar{x} = -.062$, Female: $\bar{x} = -.034$). There was also a significant effect of Time of Day ($F(1,57) = 5.01$, $p = .029$, partial $\eta^2 = .08$) which reflected a larger validity effect in the morning, compared to the afternoon (AM: $\bar{x} = -.059$, PM: $\bar{x} = -.037$). However, no other effects reached significance (all p's > .087).

For RT, the ANOVA revealed a main effect of Tranche ($F(2,114) = 8.61$, $p < .001$, partial $\eta^2 = .13$). Post-hoc paired samples t-tests demonstrated a significantly increased validity effect at the delayed tranche, compared to baseline ($t(64) = -4.23$, $p < .001$, $d = .50$) and early ($t(64) = -2.77$, $p = .007$, $d = .35$) tranches. The difference in RT between baseline and early was not significant ($p = .174$). No other effects were significant (all p's > .077).

4.4.3.4.4 Orienting Effect

Regarding accuracy, an ANOVA revealed no interaction between Tranche and Condition ($F(1.58,89.92) = .18$, $p = .781$, partial $\eta^2 = .00$), however there was a significant interaction of Tranche and Time of Day ($F(1.58,89.92) = 5.37$, $p = .011$, partial $\eta^2 = .09$). Post-hoc paired samples t-tests showed that amongst morning participants, there was a significantly increased orienting effect between the baseline and delayed tranches ($t(31) = 3.01$, $p = .005$, $d = .52$), but not between any other time-point (all p's > .055). There were no differences at any point for participants in the afternoon group (all p's > .142). No other effects reached significance (all p's > .081).

For RT, the ANOVA revealed no significant main or interaction effects (all p's > .116).

4.4.3.4.5 Flanker Effect

For accuracy, an ANOVA revealed there was no significant interaction effect of Tranche and Condition ($F(2,114) = .25$, $p = .783$, partial $\eta^2 = .00$). However, there was a significant main effect of Gender ($F(1,57) = 5.74$, $p = .020$, partial $\eta^2 = .09$) with males exhibiting a larger flanker effect overall, than females (Male: $\bar{x} = -.087$, Female: $\bar{x} = -.041$). No other effects were significant (all p's > .074).

Regarding RT, the ANOVA showed the interaction between Tranche and Condition did not reach significance ($F(2,114) = .79$, $p = .458$, partial $\eta^2 = .01$). However, there was a significant interaction effect of Tranche, Time of Day and Gender ($F(2,114) =$

4.37, $p = .015$, partial $\eta^2 = .07$). Post-hoc ANOVAs revealed a significant Tranche and Time of Day interaction amongst males ($F(1.58,40.97) = 5.07$, $p = .016$, partial $\eta^2 = .16$), but not females ($p = .543$). Paired samples t-tests demonstrated that male participants in the afternoon exhibited a reduced flanker effect between the baseline and delayed tranches ($t(12) = 2.83$, $p = .015$, $d = .30$). There were no differences between other time-points (p's > .096) or amongst males in the morning session (all p's > .086).

Contrary to predictions, no effects of Condition were observed on attentional performance. The results did however demonstrate that Gender and Time of Day can impact attentional performance. Regarding accuracy, the data showed that males experienced larger validity and flanker effects than females due to poorer performance on invalid cues / incongruent trials, whilst participants in the morning generally exhibited a larger validity effect than participants in the afternoon (again due to poorer performance on invalid cues). Further, alterations to attention over the duration of the experiment were often moderated by whether participants were tested in the morning or afternoon. To illustrate, the overall magnitude of the alerting benefit increased from the early to the delayed tranche, but only in the afternoon. Similarly, the magnitude of the orienting effect increased from baseline to the delayed tranche, but only for morning participants.

With regard to RT, it was observed that amongst males who participated in the afternoon, the flanker effect was reduced between the baseline tranche and the delayed tranche. However, this effect was not present for males who participated in the morning, nor for females. Finally, the results demonstrated that the size of the validity effect increased from baseline to the delayed tranche.

4.4.4 Physiological Influence – ANT-R Regressions.

A series of regressions were performed to investigate the possible influence of stress state and physiology on ANT-R performance.[6]

4.4.4.1 Data sanitisation

Due to incomplete or unsuitable physiological data (for details, see section 4.3.1.1) seven participants were excluded from this analysis. Additionally, as sAA and Cortisol are known to exhibit opposing diurnal cycles (Edwards et al., 2001; Rohleder, Nater, Wolf, Ehlert, & Kirschbaum, 2004), data was transformed to z-Scores in order to allow comparison between AM and PM participants i.e. AM ppts z-Score calculated as:

$$\frac{(T1\ Alpha\ Amylase - \ \bar{x}\ \boldsymbol{AM}\ T1\ Alpha\ Amylase)}{Standard\ Deviation\ of\ \boldsymbol{AM}\ T1\ Alpha\ Amylase}$$

4.4.4.2 Predictors

All regressions included Sex, WM (OSPAN), Task-focused coping (CITS) and Time of Day as predictors. For baseline tranche regressions, Condition, Trait Anxiety (STAI) and basal physiology were included (T1 sAA and Cortisol). For early and delayed tranche regressions, State Anxiety (SSAI) was included as a proxy for condition, whilst aggregated Intolerance of Uncertainty (IUS-12) was included instead of STAI to prevent issues of multicollinearity with physiology measures and SSAI. T2 sAA / Cortisol was included for early regressions, whilst T3 sAA / Cortisol was included for delayed regressions. Further, the biomarker measurements used were absolute values (as opposed to differences scores e.g. difference between T1 Cortisol and T3 Cortisol). Multiple regressions using the difference score values were computed but were not materially different from the absolute values, therefore only one is reported.

[6] The same equations were used for both accuracy and RT (e.g. Alerting = No cue – Double cue). Consequently, for **accuracy**, negative values indicate a larger effect (e.g. 90% - 95% = -5%). Thus, 'positive' relationships are represented by a negative standardised β value.

4.4.4.3 Results

Baseline: Basal physiology did not predict ANT-R performance (all *p*'s > .056). For accuracy, Trait Anxiety significantly predicted the alerting benefit ($p = .043$, $\beta = .28$ – increased anxiety related to lower benefit), whilst Sex predicted the validity effect ($p = .007$, $\beta = .36$ – larger among females), the orienting effect ($p = .048$, $\beta = .26$ – larger among females) and the flanker effect ($p = .024$, $\beta = .30$ –larger among females). OSPAN predicted the validity effect ($p = .033$, $\beta = -.30$ – larger in low WM) and Time of Day was estimated to predict the orienting effect ($p = .047$, $\beta = -.26$ – larger in the afternoon). Regarding RT, OSPAN was able to predict the flanker effect ($p = .033$, $\beta = -.32$ – smaller in high WM) (see Tables 4.5 and 4.6).

Early: Again, physiology did not predict ANT-R performance. However, for accuracy, Time of Day significantly predicted the alerting benefit ($p = .014$, $\beta = .34$ – higher in AM). Sex predicted the validity effect ($p = .014$, $\beta = .32$ – smaller in females) and the flanker effect ($p = .032$, $\beta = .27$ – smaller in females), whilst Task-focused coping predicted the flanker effect ($p = .025$, $\beta = .29$ – greater coping reduced effect). Additionally, for RT, task-focused coping also predicted the validity effect ($p = .43$, $\beta = .29$ – greater coping increased effect) (see Tables 4.5 and 4.6).

Delayed: sAA level predicted the alerting benefit (RT – $p = .040$, $\beta = -.28$ – smaller benefit in high sAA), as did State Anxiety ($p = .038$, $\beta = .33$ – larger effect in high anxiety). For accuracy, aggregated Intolerance of Uncertainty (IUS) predicted the alerting benefit ($p = .042$, $\beta = -.29$ – larger effect in high IUS), whilst Time of Day predicted the validity effect ($p = .039$, $\beta = .28$ – smaller effect in the afternoon) (see Tables 4.5 and 4.6).

The regressions suggest that physiology is not a key predictor for attentional efficiency during the periods tested. Physiology (sAA) did predict the alerting benefit in the delayed period, though this was contrary to our hypothesis that sAA would predict performance during the early tranche (SNS peak). However, earlier analyses did indicate that participants in the stress group experienced significantly increased levels of sAA,

relative to controls, for the remainder of the study following the SECPT. Therefore, the result offers very limited support for physiology influencing attention.

Similar to the ANOVAs, the regressions highlighted the influence of Time of Day and Gender. Gender was the only factor that predicted any performance measure both pre- and post-manipulation (validity effect – baseline and early). Trait and State Anxiety, Task-focused coping and Intolerance of Uncertainty however share a relationship with stress state and offered some predictive value. Nevertheless, this influence appears independent of any physiological change. Finally, WM (OSPAN) appeared to predict limited aspects of attention (validity accuracy / flanker RT) as reported by (Redick & Engle, 2006) however, these effects do not appear to be robust to time or stress exposure.

Table 4.5 *Regression table showing predictors at each tranche (baseline / early / delayed) for each of the four attentional effects (accuracy).*

Accuracy	Baseline			Early			Delayed		
	Beta	*p*	Predictor	Beta	*p*	Predictor	Beta	*p*	Predictor
Alerting Benefit	0.18	0.187	Condition	0.34	0.014 *	Time of Day	-0.08	0.538	Time of Day
	0.20	0.127	Time of Day	0.12	0.37	Gender	-0.14	0.293	Gender
	0.09	0.474	Gender	-0.12	0.422	OSPAN	0.03	0.829	OSPAN
	-0.22	0.112	OSPAN	0.07	0.608	IUS Agg	-0.29	0.042 *	IUS Agg
	0.28	0.043 *	STAI	-0.10	0.47	SSAI	0.06	0.724	SSAI
	0.16	0.237	Task Coping	-0.11	0.42	Task Coping	-0.07	0.618	Task Coping
	0.08	0.525	T1 sAA	0.04	0.752	T2 sAA	-0.24	0.071	T3 sAA
	0.06	0.675	T1 Cortisol	-0.01	0.961	T2 Cortisol	0.21	0.194	T3 Cortisol
Validity Effect	-0.14	0.297	Condition	0.20	0.116	Time of Day	0.28	0.039 *	Time of Day
	0.01	0.96	Time of Day	0.32	0.014 *	Gender	0.23	0.089	Gender
	0.36	0.007 *	Gender	0.00	0.987	OSPAN	0.03	0.841	OSPAN
	-0.30	0.033 *	OSPAN	0.25	0.056	IUS Agg	0.12	0.387	IUS Agg
	0.07	0.587	STAI	-0.09	0.521	SSAI	-0.23	0.151	SSAI
	0.04	0.774	Task Coping	-0.06	0.62	Task Coping	0.01	0.958	Task Coping
	0.01	0.971	T1 sAA	0.12	0.341	T2 sAA	0.00	0.997	T3 sAA
	0.10	0.462	T1 Cortisol	0.22	0.124	T2 Cortisol	0.12	0.464	T3 Cortisol
Orienting Effect	-0.14	0.289	Condition	-0.08	0.557	Time of Day	0.21	0.114	Time of Day
	-0.26	0.047 *	Time of Day	0.18	0.226	Gender	0.23	0.097	Gender
	0.26	0.048 *	Gender	0.02	0.907	OSPAN	0.16	0.236	OSPAN
	0.25	0.075	OSPAN	0.03	0.848	IUS Agg	0.20	0.152	IUS Agg
	-0.14	0.324	STAI	0.02	0.896	SSAI	-0.03	0.853	SSAI
	-0.08	0.569	Task Coping	-0.04	0.805	Task Coping	0.08	0.567	Task Coping
	-0.14	0.28	T1 sAA	0.12	0.423	T2 sAA	0.04	0.793	T3 sAA
	-0.01	0.93	T1 Cortisol	0.08	0.609	T2 Cortisol	0.06	0.707	T3 Cortisol
Flanker Effect	-0.01	0.926	Condition	0.22	0.081	Time of Day	0.21	0.124	Time of Day
	0.11	0.408	Time of Day	0.27	0.032	Gender	0.23	0.092	Gender
	0.30	0.024 *	Gender	-0.01	0.932	OSPAN	0.08	0.563	OSPAN
	-0.10	0.482	OSPAN	0.16	0.222	IUS Agg	0.06	0.674	IUS Agg
	0.14	0.315	STAI	0.11	0.39	SSAI	-0.02	0.911	SSAI
	0.02	0.895	Task Coping	0.29	0.025	Task Coping	0.11	0.432	Task Coping
	0.11	0.43	T1 sAA	0.14	0.287	T2 sAA	0.01	0.964	T3 sAA
	0.18	0.219	T1 Cortisol	0.12	0.401	T2 Cortisol	0.13	0.412	T3 Cortisol

* denotes significant to < .05 level

Table 4.6 *Regression table showing predictors at each tranche (baseline / early / delayed) for each of the four attentional effects (RT).*

RT	Baseline			Early			Delayed		
	Beta	*p*	Predictor	Beta	*p*	Predictor	Beta	*p*	Predictor
Alerting Benefit	-0.01	0.946	Condition	-0.13	0.352	Time of Day	0.01	0.934	Time of Day
	0.11	0.424	Time of Day	-0.21	0.121	Gender	0.07	0.579	Gender
	0.00	0.992	Gender	0.09	0.535	OSPAN	0.08	0.539	OSPAN
	-0.01	0.929	OSPAN	0.19	0.169	IUS Agg	0.09	0.52	IUS Agg
	0.21	0.146	STAI	0.06	0.675	SSAI	0.33	0.038 *	SSAI
	-0.10	0.485	Task Coping	0.12	0.397	Task Coping	-0.04	0.778	Task Coping
	-0.05	0.724	T1 sAA	-0.18	0.189	T2 sAA	-0.28	0.04 *	T3 sAA
	-0.28	0.056	T1 Cortisol	-0.02	0.911	T2 Cortisol	-0.09	0.58	T3 Cortisol
Validity Effect	-0.06	0.674	Condition	-0.07	0.595	Time of Day	-0.15	0.293	Time of Day
	-0.01	0.968	Time of Day	0.01	0.917	Gender	0.01	0.926	Gender
	-0.10	0.476	Gender	-0.12	0.418	OSPAN	-0.04	0.809	OSPAN
	-0.21	0.171	OSPAN	0.18	0.213	IUS Agg	0.09	0.544	IUS Agg
	-0.01	0.968	STAI	-0.15	0.309	SSAI	-0.01	0.957	SSAI
	0.03	0.846	Task Coping	0.29	0.043 *	Task Coping	0.09	0.554	Task Coping
	-0.09	0.541	T1 sAA	0.02	0.917	T2 sAA	-0.11	0.463	T3 sAA
	-0.10	0.518	T1 Cortisol	0.04	0.814	T2 Cortisol	-0.03	0.853	T3 Cortisol
Orienting Effect	-0.07	0.622	Condition	0.14	0.309	Time of Day	-0.03	0.851	Time of Day
	-0.13	0.353	Time of Day	0.25	0.068	Gender	0.07	0.639	Gender
	-0.13	0.365	Gender	-0.06	0.706	OSPAN	-0.04	0.77	OSPAN
	-0.09	0.556	OSPAN	0.20	0.152	IUS Agg	0.02	0.921	IUS Agg
	-0.12	0.422	STAI	-0.08	0.564	SSAI	-0.28	0.103	SSAI
	0.13	0.391	Task Coping	0.12	0.373	Task Coping	0.04	0.788	Task Coping
	0.08	0.577	T1 sAA	0.03	0.854	T2 sAA	0.03	0.826	T3 sAA
	0.07	0.649	T1 Cortisol	-0.04	0.79	T2 Cortisol	0.15	0.369	T3 Cortisol
Flanker Effect	-0.14	0.32	Condition	0.20	0.161	Time of Day	0.09	0.514	Time of Day
	0.20	0.155	Time of Day	0.09	0.537	Gender	0.13	0.366	Gender
	0.08	0.532	Gender	-0.14	0.383	OSPAN	-0.17	0.258	OSPAN
	-0.32	0.033 *	OSPAN	0.11	0.441	IUS Agg	0.08	0.608	IUS Agg
	0.07	0.622	STAI	-0.01	0.963	SSAI	0.05	0.761	SSAI
	0.00	0.987	Task Coping	0.02	0.892	Task Coping	-0.05	0.715	Task Coping
	-0.10	0.456	T1 sAA	-0.12	0.402	T2 sAA	0.04	0.81	T3 sAA
	-0.09	0.526	T1 Cortisol	-0.07	0.664	T2 Cortisol	-0.06	0.721	T3 Cortisol

* denotes significant to < .05 level

4.5 Discussion

The purpose of the present study was to investigate the impact of acute stress exposure and physiological reactivity on specific aspects of the three attentional networks (Posner & Petersen, 1990). Of further interest was whether such attentional performance was different between periods immediately following stress, or later, broadly in line with known physiological responses to exposure (SNS and HPA-Axis reactions). To this end, participants were exposed to either an acute laboratory stressor (SECPT – Schwabe et al., 2008) or to an equivalent warm water control task, and attentional performance measured before (once) and after exposure (twice) using the revised Attentional Network Test (ANT-R - Fan et al., 2009).

4.5.1 Stress induction

Effective induction of stress was measured using both self-report and physiological measures. In accordance with our hypothesis, participants unanimously reported that exposure to the SECPT was significantly more stressful, demanding and effortful relative to the control manipulation. Further, state anxiety levels were higher and performance ratings were lower. Therefore, the participants of the stress group appraised the manipulation as more stressful than their control counterparts – an important component in the measurement of stress induction (Duckworth et al., 2002; Schupp et al., 2003). Despite this, participants in the stress group did not engage in significantly greater levels of overall coping, nor specifically task-focused coping, as was predicted. An explanation for this could be the rapid administration, and the relative simplicity of the SECPT, which may not require participants to construct extensive coping strategies to assist completion of the task. Without this, although participants appraised the situation as more stressful, the may not be a need to adjust their coping mechanisms.

Further evidence supporting successful stress induction was the HPA-Axis response exhibited by stress participants following the SECPT. As hypothesised, Cortisol

production significantly increased following exposure to the stressor, peaking after approximately 20 minutes, before showing signs of recovery later in line with previous work (Dickerson & Kemeny, 2004; Kirschbaum & Hellhammer, 1989; Kirschbaum et al., 1993).

Interestingly, Alpha Amylase data was less conclusive. As the biomarker for measuring the SNS response to stress, the hypothesis stated that sAA production level would increase immediately following stress exposure (T2), before quickly returning to baseline/control levels (T3). Although control participants were not anticipated to exhibit any change in sAA level, increases were observed for both stress and control participants at T2 (following SECPT or control). There are several explanations for why this might have occurred. First, many of the control participants anecdotally remarked that their manipulation task had left them feeling deeply relaxed. Previous studies have discussed the possibility that increased parasympathetic nervous system activity could confound sAA level by impacting on salivary flow rate, making it theoretically possible that sAA concentrations could increase in response to relaxation (Jos A. Bosch, Veerman, de Geus, & Proctor, 2011; although Rohleder, Wolf, Maldonado, & Kirschbaum, 2006 previously dismissed this). Indeed, a recent study reported that when adjusting for saliva flow rate, magnitude of sAA responses was "robustly" altered (Nagy et al., 2015). Additionally, Bosch and colleagues (2011) also reported that sAA concentration levels could potentially be impacted by greater sAA release via predominantly PNS-innervated glands (e.g. sublingual glands) or as a result of synergistic interactions between the SNS and PNS, where PNS activity amplified the SNS effects. In the present experiment, a likely explanation could be that higher than expected levels amongst controls resulted from a pre-emptive stress response as participants anticipated an unpleasant task (Bosch et al., 1996; Robinson et al., 2013). Although blind to their condition, participants were informed at briefing that they would need to immerse their hand in warm or cold water. It may have

been that participants (predominantly Psychology students) anticipated the unpleasant version of the task and reacted accordingly.

More importantly, participants in the stress group demonstrated a typical stress response, with sAA significantly increasing immediately following the SECPT (T2). However, sAA levels also remained higher for the duration of the experiment (T3 and T4). Although unusual, the results do indicate a physiological response to stress and previous literature has demonstrated that activation of physiological systems following stress does not always match subjective experience (Robinson et al., 2008; Van Dijk, Westerink, Beute, & Ijsselsteijn, 2015). When viewed alongside an archetypal self-reported reaction to stress exposure, it seems safe to assume stress was successfully induced.

4.5.2 ANT-R performance

ANT-R performance measurements of accuracy and RT were recorded in three tranches; baseline (four full blocks of the ANT-R), early and delayed (two blocks each). The latter two time-points were designed to capture performance during immediate and delayed periods following stress exposure, broadly reflecting the time course of the SNS and HPA-Axis, physiological pathways activated by stress. The approach of splitting the ANT-R has been considered previously outside of stress research, by Greene et al. (2008) who demonstrated moderately reliable correlations across the three networks. In the present experiment, split-half reliabilities showed significant correlations across all cue and flanker types, offering support for the approach.

It was anticipated that performance amongst controls would remain consistent across repeated ANT-R tasks as past research has found performance to be stable over as many as ten iterations (Ishigami & Klein, 2010). However, contrary to these expectations, performance changes over time were observed for both global Accuracy and RT, thus complicating interpretation of genuine effects of stress on attentional performance. However, it should be highlighted that these changes were prevalent amongst both stress

and control participants (i.e. no interaction of Tranche and Condition). Therefore, it appears that even though participants may have experienced a different manipulation, their overall performance evolved in a similar manner.

4.5.2.1 Stress and the ANT-R

Regarding the original hypotheses, exposure to an acute psychosocial stressor did not significantly alter performance from controls, either immediately following exposure or in a delayed period, in any of the four attentional effects measured. Previous literature has suggested that attentional alerting is improved following exposure to stress due to hypervigilance (Dandeneau et al., 2007; Helton et al., 2009; Roelofs et al., 2007; Weymar et al., 2012) which was also expected to influence the validity and orienting effects. Other work, including the pilot study, has suggested that distractibility should increase, particularly in response to invalid cues (Elling et al., 2011; Weymar et al., 2012). Despite this, no significant changes were observed. Furthermore, in spite of existing literature indicating that the Flanker Effect should reduce as a result of attentional narrowing, or enlarge due to a broadening of attention (Alomari et al., 2015; Chajut & Algom, 2003; Elling et al., 2011; Robinson et al., 2013; Schoofs et al., 2008; van Steenbergen et al., 2011) no differences were observed between stress participants and controls. Although not a unique finding (Tarazona et al., 2013), it is surprising that the present study found no evidence of differences between stress and controls on any of the attentional networks examined. It is possible that control performance evolving across multiple iterations of the ANT-R, contrary to expectations (Ishigami & Klein, 2010), could have potentially hidden an influence of stress. To illustrate, the presence of an alerting benefit immediately post-stress could have been moderated by a learning effect amongst Controls. The design of the study meant that participants completed their three attempts at the ANT-R in quick succession. Therefore, it might be that any benefit to vigilant attention following stress could have been offset by the control participants also becoming more skilled at the task.

Similarly, any decrements to performance resulting from stress, particularly in the latter attempt, could have been countered by control participants becoming fatigued or bored with the ANT-R. Further, with task performance close to ceiling (e.g. accuracy ~ 96%), any potential for improvement was limited.

Although the primary investigation was whether exposure to an acute psychosocial stressor would affect ANT-R performance, of further interest was the influence of the subsequent physiological reaction on attention. A series of regressions demonstrated little influence of physiology, except in the third, 'delayed' tranche of the ANT-R. At this time-point, higher sAA level, an SNS biomarker of stress (Nater & Rohleder, 2009; Rohleder et al., 2004) was related to a reduced alerting benefit amongst participants. Interpretation of this result is problematic for two reasons: 1) sAA initially increased across both groups, and 2) the result occurred at a time when sAA was expected to have returned to baseline levels, even amongst stress participants. However, though it is true that both Control and Stress participants exhibited increased sAA initially, further examination of the results indicated that sAA only remained high for participants in the stress group. Although contrary to our expectations, this is important for interpreting the regression data as it indicates that activation of a discrete physiological pathway (the SNS) is related to smaller alerting benefits, relative to those with lower sAA activation (controls). This does not support the original hypothesis that the alerting benefit would increase following exposure to stress. However, much of the research that reported an increase in alerting or vigilant attention was constrained to emotional cuing or negative affect (Dandeneau et al., 2007; Roelofs et al., 2007; van Steenbergen et al., 2011). Alternatively, one study by Alomari and colleagues (2015) reported that reaction time was impaired on the SART following stress exposure, where participants are expected to respond to the presence or absence of a target. The observation from the regression would appear to offer some support for this finding.

4.5.2.2 Other factors and the ANT-R

Although there was limited evidence for the effects of stress on attention, several related factors were associated with altered attentional performance. To illustrate, the validity effect was reduced during the early tranche amongst those who engaged in greater levels of task coping. Further, the alerting benefit was observed to be lower amongst people with high trait anxiety (baseline accuracy) but higher amongst those with higher intolerance of uncertainty during the delayed tranche (RT). However, the stress and control groups did not significantly differ on these variables. Interestingly, those who demonstrated higher state anxiety (i.e. stress participants) did exhibit increased alerting benefits during the delayed tranche (RT), offering support for the original hypothesis that alerting benefit would be improved by exposure to stress.

Another factor that appeared to share a relationship with attentional performance was working memory (OSPAN). Previously, Redick and Engle (2006) demonstrated that individuals with higher working memory capacity demonstrated better control of attention and therefore a reduction in interference of the executive control network. Similarly, we report that individuals exhibiting higher OSPAN scores showed reduced flanker interference, as well as a reduced validity effect, during their baseline run of the ANT-R – indicative of superior attentional control.

Time of Day did appear to interact with attentional performance. Previous work has shown that testing attention of young adults in the morning elicits different results to when testing in the afternoon, specifically on the alerting network (Knight & Mather, 2013). Time of Day was also of particular interest in the present study given the competing diurnal cycles of sAA and Cortisol (Edwards et al., 2001; Nater, Rohleder, Schlotz, Ehlert, & Kirschbaum, 2007; Ross, Murphy, Adam, Chen, & Miller, 2014).

It was demonstrated that Time of Day impacted the validity effect in the present study; with the validity effect larger amongst participants in the morning. Further examination of components used to calculate the validity effect reveals that accuracy on

invalid cues was not only poorer than valid cues, but also much poorer in the morning than in the afternoon, resulting in the enlarged validity effect (for raw data see Appendix C). One explanation could be increased alertness in the morning as a result of the Cortisol awakening response (Edwards et al. (2001), which could lead to an increase in false alarms on invalid trials. Although not offering direct support to Knight & Mather's 2013 findings, the results appear to reinforce their findings.

Additionally, there were interactions between Time of Day and ANT-R performance (over three tranches) on both the alerting and orienting networks (both accuracy), as well as a three-way interaction with Gender on the executive control network (RT). Data showed that afternoon participants exhibited enhanced alerting benefits post-manipulation (early to delayed), whilst morning participants demonstrated a larger orienting effect from their first ANT-R to their last (baseline to delayed). Additionally, when tested in the afternoon, males exhibited a reduced flanker effect over time (baseline to delayed). Such results offer little support to Knight & Mather (2013), although it is difficult to compare the two studies directly due to the earlier study employing only a single attention task, whilst current data takes into account multiple runs of the ANT-R.

Previous studies have reported gender differences in attention (Bayliss, Pellegrino, & Tipper, 2005; Merritt et al., 2007) and stress response (Kirschbaum et al., 1999). Therefore, it was not unexpected to observe Gender influenced overall ANT-R performance, with males demonstrating larger validity and flanker effects (accuracy) than females. Whilst existing literature has reported a gender difference in Posner-style cuing tasks when using endogenous cues (Merritt et al., 2007), it is thought to be the first report of gender differences when using the exogenous cues used in the present study. The above results demonstrate the importance of carefully accounting for both Time of Day and Gender in any future studies exploring attention.

The results offer strong evidence that stress was successfully induced following the SECPT. HPA-Axis physiology and self-report measures evolved in the hypothesised

manner and whilst sAA presented an atypical response amongst controls, the response amongst stress participants was equally strong and endured for a longer period, highlighting the effect of exposure to the SECPT. Although ANT-R performance revealed no group differences due to stress exposure, differences due to Gender and the Time of Day were evident. There was limited evidence for the direct influence of physiological reactivity on ANT-R performance, as high levels of sAA shared a negative relationship with alerting efficiency. The data therefore indicated that any benefit from the appearance of a cue was reduced when sAA levels, and thus SNS activity, were high. However, other factors related to stress state (state anxiety and coping), or susceptibility to stress (trait anxiety and intolerance of uncertainty) did offer some predictive value at various points during the experiment. Despite this, the results are not necessarily linked to the experimental experience and therefore should be considered with caution.

4.5.3 Limitations

As the intention of the current study was to examine various types of attention across discrete, time-constrained periods following exposure to stress, the ANT-R was the most appropriate for the study. The task is relatively quick to administer (~ 30 mins), has shown good test-retest reliability (Hahn et al., 2011), and allows exploration of multiple facets of attention within a single task. Nevertheless, several issues require scrutiny. The task itself comprises of 288 trials, with each participant in the present study completing the equivalent of two full runs, or 576 trials. However, as difference scores are calculated from specific trial types, the number of trials used to calculate each measure is considerably smaller. The issue is further compounded by the use of "split-half" runs to capture early and delayed performance post-stress. In spite of this, split-half reliabilities demonstrated excellent correlation validating such an approach. However, future studies aiming to examine factors that might influence performance across different attentional

networks would benefit from using the ANT-R to identify the most appropriate networks for further investigation, before developing a more specified task to improve power.

Ishigami and Klein (2010) reported that performance on the ANT-R remained relatively stable over as many as 10 iterations, despite some limited evidence of practice effects on the orienting and executive control networks. In the present study, control performance was subject to both practice and fatigue effects, thus limiting our ability to interpret any differences to stress participants as solely the responsibility of stress exposure. Future work intends to limit each participant to a single post-manipulation run of the ANT-R, either in the immediate (early) or delayed aftermath of stress exposure, so as to minimise the effects of both practice and fatigue.

The SECPT has been repeatedly validated as a psychosocial stressor (Schwabe et al., 2008; Skoluda et al., 2015). Most important to the present study was the rapid administration, making it preferable to other popular stressors such as the Trier Social Stress Test (~20 mins - Kirschbaum et al., 1993). Administration of the SECPT resulted in clear differences between the groups in both self-report and Cortisol measures. However, salivary Alpha Amylase data was inconsistent, as controls also exhibited elevated sAA, which increases the difficulty of interpretation. Such data might easily be explained as anticipatory stress, resulting from controls being blind to their condition and wrongly anticipating the cold-water variant of the task. However, other explanations related to the sensitivity of sAA as a measure, and the possibility that parasympathetic nervous system (PNS) activity could have influenced sAA measures should be considered. For instance, Bosch et al. (2011) reported that sAA levels could be increased either as a product of an interaction between SNS and PNS activity, or as sAA is released from glands predominantly innervated by the PNS. Alternatively, sAA concentration can be impacted by saliva flow rate, which is mediated by the PNS. In the present experiment, control participants could have felt relaxed by their experience of placing their hand in warm water, which could have activated increased PNA activity and introduced higher than

expected sAA levels. Attempts to reduce such a possibility in future should therefore, not only consider making control participants aware of their 'control' status, but also consider additional validated markers of SNS activity, such as Heart Rate measurement, pulse oximetry or skin conductance, in order to authenticate the stress response.

Finally, interpretation was complicated by confounding factors including participants being measured at opposing times of the day and gender differences, both known to impact not only on attentional performance (Knight & Mather, 2013; Merritt et al., 2007), but also the physiological stress response (Dickerson & Kemeny, 2004; Kirschbaum et al., 1999; Verma, Balhara, & Gupta, 2011). Future work will benefit from a design that tests individuals at a single time of day, or that focuses on each gender individually, in order to reduce further complications of interpretation and improve power.

4.5.4 Conclusion

The purpose of the present study was to explore if, and how, exposure to an acute psychosocially stressor influenced attention, and whether such change was moderated by time from stress exposure – broadly in line with known physiological reactions to stress. Instead, the results indicate that factors such as Time of Day, Gender, and the effects of practice or fatigue influence attentional performance to a greater extent than the magnitude of any physiological response. That being said, exposure to stress did lead participants to appraise their situation as more distressing and exhibit increased physiological reactions that in one instance appeared to relate to changes on the alerting network of attention. Improved experimental design could elucidate this, and other effects of stress if the aforementioned factors are better accounted for and controlled. This will form the basis of Experiments Two and Three, in the hope of clarifying the effects of stress and its associated time course, in order to develop a clearer understanding of how stress influences attention.

5 Experiment Two

5.1 Chapter Overview

Experiment One examined attentional network performance following exposure to the Socially Evaluative Cold Pressor Task (SECPT). Despite strong evidence supporting the induction of stress, efficiency measures on the ANT-R failed to demonstrate any significant difference between control and stressed performance. One explanation for this result was that participants were required to complete multiple ANT-R's in quick succession. Although control performance was anticipated to remain stable across these iterations, there was evidence for effects of practice and fatigue across the duration of the experiment that may have masked effects of stress. The purpose of Experiment Two is to incorporate a design that minimises such effects by requiring participants to complete only one post-stress ANT-R. The previous experiment also showed a substantial influence of participant Gender on stressed attentional performance. Therefore, examination of these gender effects will continue to be of interest in the present study. Most importantly, Experiment One highlighted the confounding effect of Time of Day (AM or PM) on both stress response and attentional performance. Therefore, Experiment Two limits its examination to afternoon effects in order to minimise the known impact of the Cortisol Awakening Response (CAR).

5.2 Introduction

Existing research has extensively examined the effects of acute stress on various aspects of attention. However, the representativeness of this research is limited in scope by the preference to either measure only discrete aspects of attention, or utilise highly specific tasks (Alomari et al., 2015; Elling et al., 2011; Sänger et al., 2014; Scholz et al., 2009). For this reason, the present series of experiments used the Attentional Network

Task – Revised (ANT-R) in an attempt to improve the representativeness of any findings. The original ANT was designed to "evaluate alerting, orienting and executive attention within a single 30-minute testing session" with the intention that it should be both simple to administer and easy to complete (Fan, McCandliss, Sommer, Raz, & Posner, 2002 - p.340). Designed to examine those multiple aspects of attention within a single measure, the ANT-R is more likely to realistically represent the attentional challenges encountered day-to-day than a more highly specified laboratory experiment. According to Fan and colleagues, the original ANT produced significant test-retest reliability whilst others have commended the tools validity given its use of well-established and reliable measures of subcomponents of attention including the Posner cueing and Eriksen flanker paradigms (Macleod et al., 2010). Further, reviews of both the ANT and ANT-R have stated that individual network scores remained significant after as many as ten iterations and that power is improved by repeat administration of the task (Ishigami & Klein, 2010; Macleod et al., 2010).

Data reported in Experiment One showed that although both global accuracy and RT remained significantly correlated across multiple runs of the ANT-R, the functioning of the networks (difference scores) were not as stable and changed for both control and stress participants, contrary to expectations. Examination of these changes indicated that participants in the control group were susceptible to effects of both practice and fatigue and that these might have potentially hidden changes due to acute stress exposure. The likelihood of experiencing effects of practice and fatigue was increased by the requirement for participants to complete two separate runs of the ANT-R in quick succession following exposure to the SECPT or control task. Therefore, the present study reduces the potential for this confound by randomly assigning participants to complete only one run of the ANT-R following administration of the manipulation.

In line with Experiment One, the post-manipulation ANT-R will be administered in one (of two) periods related to the known physiological reaction to acute stress exposure.

These are the Sympathetic Nervous System (SNS) regarded to be active in first 15 minutes following acute stress, and the Hypothalamic Pituitary Adrenal (HPA) Axis, which peaks in activity approximately 20-30 minutes post-stress (Herman & Cullinan, 1997). Whilst the intention is to reduce the potential for practice or fatigue to contribute to performance, the design will also allow delineation of performance within these discrete periods and explore whether active physiological responses contribute to attentional performance, an original aim of Experiment One.

Knowledge of these underlying physiological responses to stress has also guided previous literature to conduct experiments during the afternoon (Luethi et al., 2009; Lupien et al., 2002; Skoluda et al., 2015). Cortisol, the preferred method of measuring successful stress induction, has long been understood to follow a diurnal cycle, with levels dropping towards the end of the day and reaching their peak in the last hours of night-time sleep (Pruessner et al., 1997; Smyth et al., 1997). However, in the 45-60 minutes following awakening Cortisol levels typically rise steeply in what is known as the Cortisol Awakening Response (CAR), before beginning the steady decline over the course of the day (Ross et al., 2014). Cortisol has long been established as a useful marker of HPA-Axis activity, and CAR is often cited as a motive for conducting stress-based studies in the afternoon, given that the CAR can increase Cortisol levels by 50-100 % whilst levels of Cortisol in the afternoon tend to be lower and more stable (Kudielka et al., 2012).

In Experiment One attentional data was collected in both morning and afternoon sessions. Despite this, the expected Cortisol response to acute stress (i.e. increase approximately 30-minutes post-stress, followed by recovery) was observed amongst participants in the stress group. Further, there were no significant differences in response profile between participants tested in the morning and the afternoon. However, analyses considered changes from participants Cortisol levels at the beginning of the study and it is likely that these baseline levels were different for participants in the morning compared to those in the afternoon. Differences between 'basal' Cortisol levels of participants at these

two points of measurement could potentially explain the 'Time of Day' effects observed across each of the attentional networks in Experiment One. For these reasons, Experiment Two measures the effects of acute stress on attentional network performance exclusively in the afternoon.

5.2.1 Gender differences

In addition to the Time of Day effects, Experiment One also showed that participant gender was able to exert a demonstrable influence on stressed attentional performance. This was not wholly unexpected given that gender differences have been reported for both attentional performance (Merritt et al., 2007), including on aspects of the ANT (Liu et al., 2013), as well as stress reactivity (Kirschbaum et al., 1999; Ordaz & Luna, 2012) and therefore would reasonably be expected to occur when measuring stressed attention.

For instance, a 2011 EEG study examined gender differences in visual reflexive attention shifting and reported a significant difference between male and females (Q. Feng et al., 2011). Specifically, when engaged in a spatial cueing task, females showed a much larger ERP component amplitude than males. The authors hypothesised that this was due to females experiencing a larger cueing effect than males, thus causing them to use more attentional resources to complete the task successfully (see also Merritt et al., 2007). This supported earlier work by Bayliss and colleagues who reported gender differences in both eye gaze and symbolic cueing of attention (Bayliss et al., 2005). In their study, when observing a face with averted eyes, males demonstrated less of a reflexive shift of attention (toward the "gazed at" location) than females. A further experiment replicated the results when non-informative arrows were used as a central cue, rather than eyes. However, two other experiments by the authors showed no gender differences in exogeneous orienting when using peripheral cueing. The researchers concluded that although peripheral cueing is equivalent across male and female brains, the attention system treats non-informative

symbolic cues differently. Other work has presented similar differences between males and females when exploring other aspects of visual attention (Lykins, Meana, & Strauss, 2008).

Empirical evidence has suggested that these gender differences may occur as a result of different development rates between males and females. For instance, a large US study (n = 2200) examined gender differences in school children aged 5-17 years old (Naglieri & Rojahn, 2001). The study employed the Cognitive Assessment System and the data showed that females outperformed males on both planning tasks and attention tasks. Similar results were reported by Sussman and Tasso (2013) who observed that female school children displayed greater attentional capacity than males when completing a continuous performance test. Relying on this interpretation, Feng et al. proposed that the difference they reported in ERP magnitude in their spatial cueing task could be due to the fact that females mature earlier. The authors implied that what they observed might just have been "more mature activation patterns, with enhanced amplitude in these regions" (Feng et al., 2005 – p. 59).

Notwithstanding the examples above, the literature regarding gender differences in visual attention is reportedly mixed (Valian, 1999), with other researchers reporting no differences in attention between males and females, with one example offered by (Seidman et al., 2005). In this study, the researchers explored gender differences in pre-teens and teenagers both with and without ADHD. Whilst there were clear differences between the ADHD and non-ADHD children, there were no differences observed between males and females, neither amongst the ADHD group, nor the control group. Similarly, Brosch, Sander and Scherer (2007) measured attentional capture by emotional images and found that attention was captured equally well by both males and females.

One possible explanation for the inconsistent results was postulated by (Dye & Bavelier, 2010) who explored visual attention in school children and young adults (7-22 years old). The researchers tested three different aspects of visual attention and observed

distinct developmental trajectories for each. In fact, whilst gender differences were minimal amongst younger children, the gap in performance appeared to grow by adulthood. This difference appeared to function as a result of video game playing, where males showed improved attention that was related to their increased exposure to video games. Such a finding is not unique, as a 2007 study by J. Feng, Spence and Pratt (2007) reported apparent gender differences in spatial attention were eliminated following just 10 hours of training on a video game.

Additionally, gender differences have been extensively reported across the stress literature, particularly as sex differences are known to impact the stress response (Verma et al., 2011). Kirschbaum et al. (1999) reported that the HPA-Axis response to stress is heavily mediated not just by sex, but also more specific factors such as the menstrual cycle in females (further support by Kudielka & Kirschbaum, 2005; see also Ordaz & Luna, 2012). Furthermore, cognitive differences between males and females following exposure to acute stress have also been reported.

Hoskin, Hunter and Woodruff (2014) examined auditory selective attention and reported that females generally displayed greater distractibility than males. However, following exposure to acute stress, whilst both males and female's selective attention was improved when listening to emotionally-neutral auditory stimuli, only females improved when presented with tonal stimuli. This would suggest that stressed female's selective attention improved to a greater extent than males who were stressed. Further, a different study by Mather and Lighthall reported that whilst gender differences are commonplace with regard to strategy selection during risky decision making, these differences are amplified following stress (Mather & Lighthall, 2012), repeating the findings of Preston, Buchanan, Stansfield and Bachara (2007) and van den Bos, Harteveld and Stoop (2009) (both cited in Mather & Lighthall, 2012). Almela et al. (2011) examined how stress reactivity influenced memory and again reported that gender played an important role. Following a psychosocial stressor (TSST) memory performance was significantly poorer

for females, but not males. Additionally, poorer memory performance was also related to earlier sexual maturation, further emphasizing the importance of sex/gender on stress performance.

However, there is also limited evidence that whilst exposure to stress introduces some distinct physiological changes between males and females, this does not extend to different cognitive performance (Tarazona et al., 2013). To our knowledge, no previous work (with the exception of Experiment One) has examined gender differences in attentional network performance following stress. For this reason, gender will continue to be examined in the present experiment, in the hope of elucidating how it affects stressed performance on the ANT-R.

5.2.2 Hypotheses

The hypotheses for Experiment Two matched those of Experiment One:

1) Exposure to the SECPT will result in greater levels of self-reported stress than those participants subjected to a warm water control task and require significantly higher levels of coping, particularly task-focused coping.

2) Exposure to the SECPT will produce the typical physiological response with regard to the SNS (higher levels of sAA amongst stress, peaking immediately following SECPT) and the HPA-Axis (higher levels of Cortisol, peaking in the delayed period following SECPT).

3) Participants in the stress group will demonstrate enhanced alerting (RT), relative to controls, at both the early and delayed periods.

4) Participants in the stress group will demonstrate reduced validity effects (RT), relative to controls.

5) Participants in the stress group will demonstrate reduced orienting effects (RT), relative to controls.

6) The flanker effect of participants in the stress group will differ from controls following stress. If stress results in narrowed attention, participants will demonstrate a reduced flanker effect (accuracy and RT). However, if stress instead impairs decision making, the magnitude of the flanker effect will be enlarged (accuracy and RT).

7) Higher levels of physiological biomarkers (sAA and Cortisol) will be positively correlated with the attention changes detailed above.

5.3 Method

5.3.1 Participants

Sixty healthy men and women aged 18 to 33 ($\bar{x}$ *age* = 19.87 yrs, *SD* = 2.57 yrs) participated and were assigned – using a randomised block design – to either a control condition (Warm Pressor Task: *n* = 29, [20 female], $\bar{x}$ age = 19.8 yrs, SD = 2.16 yrs), or a stress condition (SECPT: *n* = 31, [20 female], $\bar{x}$ age = 19.9 yrs, SD = 2.95 yrs). Participants were students or staff at the University of Southampton and recruited via the university's online research portal and on-campus advertisements. All participants provided written informed consent. Upon termination of their session they were compensated with a maximum of £18 or credits towards partial fulfilment of their course requirements.

5.3.1.1 Exclusions

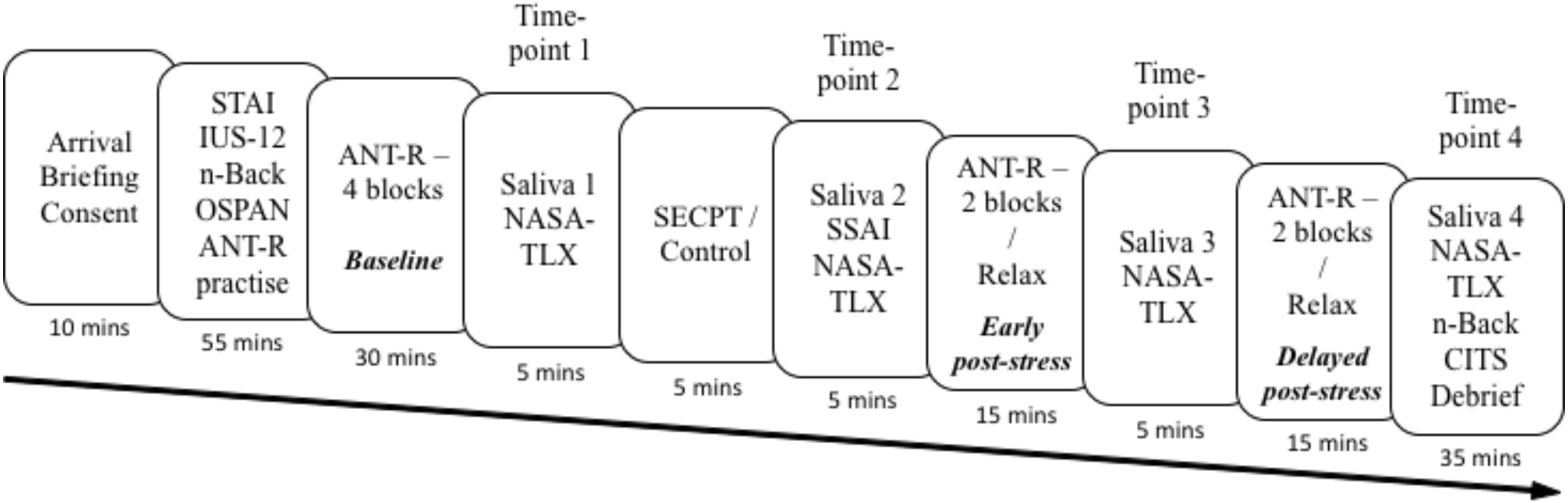
Exclusionary criteria matched Experiment One, and is described in Chapter Three – Methodology. All participants achieved the minimum level of accuracy (Baseline) established in Chapter Three and therefore were included in the initial data analyses (*n* = 60).

Regarding the examination of physiological responses (ANOVA) and how physiology influenced ANT-R performance (regressions), four participants were excluded as a result of their basal physiological data exceeding 2 SDs from the mean (*n* = 56).

5.3.2 Apparatus and Procedure

Apparatus and the procedure are also detailed in Chapter Three – Methodology and closely matched Experiment One. However, in the current experiment participants were required to complete only one post-stress run of the ANT-R, either during the early period (0-15 mins) or the delayed period (20-35 mins). During the non-test period, the participant was instead invited to spend 15 minutes relaxing in the laboratory by sitting in a recumbent position and engaging in some light reading if they wished. All were asked to refrain from using electronic devices or from engaging in work related to their university studies. Participants were assigned to either an 'early' or 'delayed' condition using a randomised block design. Experimental sessions commenced at 12:50 or 13:00 and the order of tasks can be seen in the experiment schematic on the next page (Figure 5.1).

Figure 5.1 Runtime order for Experiment Two



Schematic detailing the order of tasks that participants experienced during Experiment Two. The task order was identical to Experiment One except participants engaged in one post-stress run of the ANT-R (instead of two). Participants were randomly assigned to testing in either the "early" or "delayed" period. Their non-test period was instead filled with 15 minutes of relaxation where they sat in a recumbent position and engaged in some light reading.

5.4 Results

5.4.1 Analysis design

As per Experiment One, Greenhouse-Geisser corrected degrees of freedom were used in all analyses where the assumption of sphericity was violated. Reported effect sizes include partial η^2, Cohens *d* and Glass's *Delta*. To simplify the analyses, participants ANT-R data was organised such that – regardless of actual order – T3 represented the post-stress relaxation period and T4 represented the post-stress ANT-R. Analyses were conducted in the same manner as Experiment One:

1) examination of group differences and success of stress manipulation;

2) examination of ANT-R performance globally, and post-manipulation, accounting for differences between early and delayed periods and gender;

3) examination of any direct influence of physiology (or other factors) on ANT-R performance.

The data and a full set of analyses outputs is available in Appendix D.

5.4.2 Groups – Stress vs Controls

Independent samples t-tests revealed no significant differences between the stress and control groups in gender, birth control, age, handedness, trait anxiety, intolerance of uncertainty, or working memory (OSPAN). Furthermore, an equal number of participants was tested in the "Early" and "Delayed" periods (all *p*'s > .073).

In line with expectations, participants in the stress condition spent a significantly shorter amount of time with their hand immersed in water than control participants (control $\bar{x}$ *= 180 seconds*, stress $\bar{x}$ *= 164.97 seconds*) ($t(30) = 2.07$, $p = .047$, *Glass's* $\Delta = 15.03$).

5.4.2.1 Self-report measures

An independent samples t-test demonstrated a significant difference between stress and controls in State Anxiety (SSAI) immediately following the SECPT/control

manipulation ($t(44.92) = -5.47$, $p < .001$, $d = 1.40$). As hypothesised, participants in the stress group reported significantly higher levels of state anxiety immediately following the SECPT, than controls who completed the equivalent task with warm water.

A series of 2 (Condition: Stress vs Control) x 4 (Time-point: T1 to T4) x 2 (Stress time-course: Early vs Delayed) repeated measures ANOVAs were performed on each of the seven (modified) NASA-TLX measures, with an interaction of Condition and Time-point of interest. Significant interaction effects of Condition and Time were observed for each measure (all F's > 16.49, all p's < .001, partial η^2's > .23), except Temporal Demand ($F(2.22,124.16) = 2.01$, $p = .133$, partial $\eta^2 = .04$) and Performance ($F(2.15,120.59) = 2.19$, $p = .113$, partial $\eta^2 = .04$). However, planned comparisons using independent samples t-tests showed that significant differences were present for each measure immediately following the stressor (T2: all p's < .002, all *Glass's* Δ's > 1.52 – T2 means are shown in Table 5.1). Each difference appeared in the hypothesised direction with workload measures significantly higher amongst stress participants and performance satisfaction lower. Surprisingly, there was also a significant difference between stress and controls in Mental Demand during the "Relaxation" period (T3: $t(37.82) = -2.51$, $p = .017$, *Glass's* Δ = 1.36), indicating that exposure to the SECPT resulted in legacy "stress" effects during the "relaxation" period (regardless of Early/Delayed condition). Importantly however, examination of the means suggests that despite the significant difference, the relaxation period was not substantially demanding for either group (control $\bar{x} = 2.45$; stress $\bar{x} = 6.03$ (out of a possible 100)). No other workload measures were significant at any other time (all p's > .076).

Table 5.1 *Mean (SD) ratings by participants on Spielberger State Anxiety Index (SSAI – scores 0-80) and NASA-Task Load Index (scores 0-100) immediately following stress exposure or control (T2).*

		SSAI	Mental	Physical	Temporal
Condition	*n*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	29	28.86 *(5.06)*	3.9 *(4.17)*	10.79 *(14.35)*	5.93 *(6.43)*
Stress	31	40 *(10.06)*	56.71 *(29.58)*	78.97 *(18.07)*	24.26 *(26.75)*

		Performance	Effort	Frustration	Stress
Condition	*n*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	29	91.55 *(10.46)*	5.28 *(4.93)*	5.55 *(8.01)*	6.07 *(9.32)*
Stress	31	75.68 *(31.4)*	75.29 *(21.85)*	42.45 *(27.34)*	58.97 *(26.39)*

A 2 (Condition) x 3 (Coping) x 2 (Stress time-course) repeated measures ANOVA examined coping strategies and demonstrated a significant interaction effect of Condition and Coping ($F(1.8,100.70) = 11.16$, $p < .001$, partial $\eta^2 = .17$). Post hoc independent samples t-tests showed that stress participants engaged in significantly higher levels of task-focused coping ($t(50.38) = -3.84$, $p < .001$, Cohens $d = 1$) and emotion-focused coping ($t(48.22) = -2.96$, $p = .005$, $d = .76$) than controls. There was no difference in avoidance-focused coping ($p = .162$). In line with our original hypothesis, participants in the stress group engaged in significantly greater levels of task-focused coping, as well as emotion-focused coping compared to their control counterparts.

5.4.2.2 Alpha Amylase

For sAA reactivity, there was a main effect of Time ($F(2.21,105.95) = 14$, $p < .001$, partial $\eta^2 = .23$). Post hoc paired samples t-tests indicated that sAA level increased from T1 to T2 ($t(55) = -5.9$, $p < .001$, *Glass's* $\Delta = .85$), T3 ($t(55) = -3.25$, $p = .002$, *Glass's* $\Delta = .29$) and T4 ($t(55) = -2.77$, $p = .008$, *Glass's* $\Delta = .25$). However, participants also demonstrated significant reductions from T2 to T3 ($t(55) = 4.62$, $p < .001$, $d = .35$) and T4 ($t(55) = 4.47$, $p > .001$, *Glass's* $\Delta = .34$). The difference between T3 and T4 was not

significant (p = .657). These results suggest that regardless of Condition, participants experienced an increase in sAA, that peaked at T2, but remained at a significantly higher level than baseline for the duration of the experiment, mirroring the results reported in Experiment One (Chapter Four). The interaction between Time and Condition did not reach significance (F(2.21,105.95) = .78, p = .471, partial η^2 = .02), however planned paired samples t-tests exploring each Condition independently did illuminate subtle differences. Specifically, stress participants demonstrated significantly increased sAA levels from T1 to T2 (t(28) = -4.4, p < .001, d = .58), T3 (t(28) = -3.51, p = .002, d = .30) and T4 (t(28) = -2.21, p = .036, d = .17). Conversely, Control participants only demonstrated a significant sAA increase from T1 to T2 (t(26) = -3.86, p = .001, d = .58) (see Figure 5.2). Contrary to our predictions, but in line with data observed in Experiment One, the results indicate that participants in both the stress and control groups exhibited an increase in sAA immediately following the manipulation (T2). However, only amongst stress participants did this increase remain significantly higher at subsequent points in the experiment (T3 and T4), as controls returned to baseline levels. This suggests that although both groups of participants indicated increased sAA, only exposure to the SECPT resulted in prolonged elevation to sAA level (for means see Table 5.2).

Figure 5.2 Salivary Alpha Amylase values at four time-points.

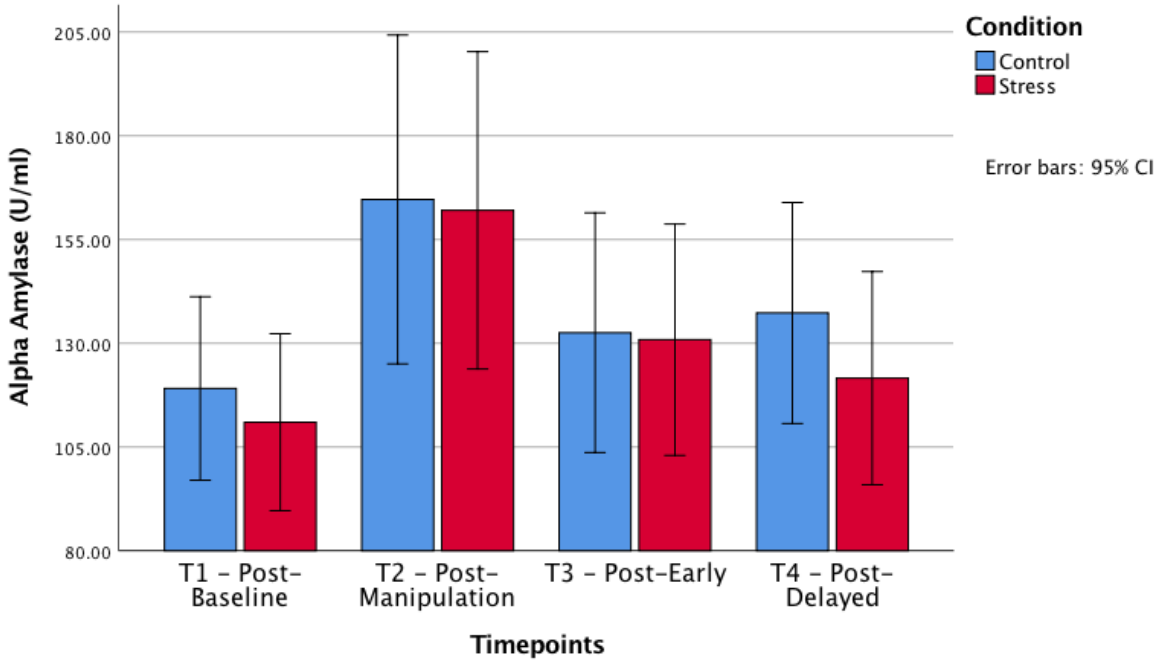


Figure 5.2. Graph demonstrates control and stress participants experienced elevated sAA at T2 (compared to T1). However, stress participants sAA was also significantly higher at T3 and T4. This was not the case for Control participants.

5.4.2.3 Cortisol

For Cortisol reactivity, there was a significant main effect of Time ($F(1.74,83.28) = 4.4$, $p < .019$, partial $\eta^2 = .08$) and a significant interaction effect of Time and Condition ($F(1.74,83.28) = 5.97$, $p = .006$, partial $\eta^2 = .11$). Planned paired samples t-tests examining each Condition individually showed that whilst control participants Cortisol level did not significantly differ across time-point (all p's > .244), stress participants Cortisol significantly increased from T1 to T3 ($t(28) = -3.25$, $p = .003$, $d = .83$) and T4 ($t(29) = -2.42$, $p = .022$, $d = .60$) (but not T2 – $p = .342$). These results support our original hypotheses' that participants in the stress group would experience a significant increase in Cortisol at T3 following exposure to the SECPT. Furthermore, it indicates that Cortisol remained at an elevated level throughout the "delayed" period, albeit showing signs of recovery, thus matching the results of Experiment One (Chapter Four) (see Figure 5.3). There were no other significant interaction effects in the ANOVA (all p's > .153) (for means see Table 5.2).

Figure 5.3 Salivary Cortisol values at four time points.

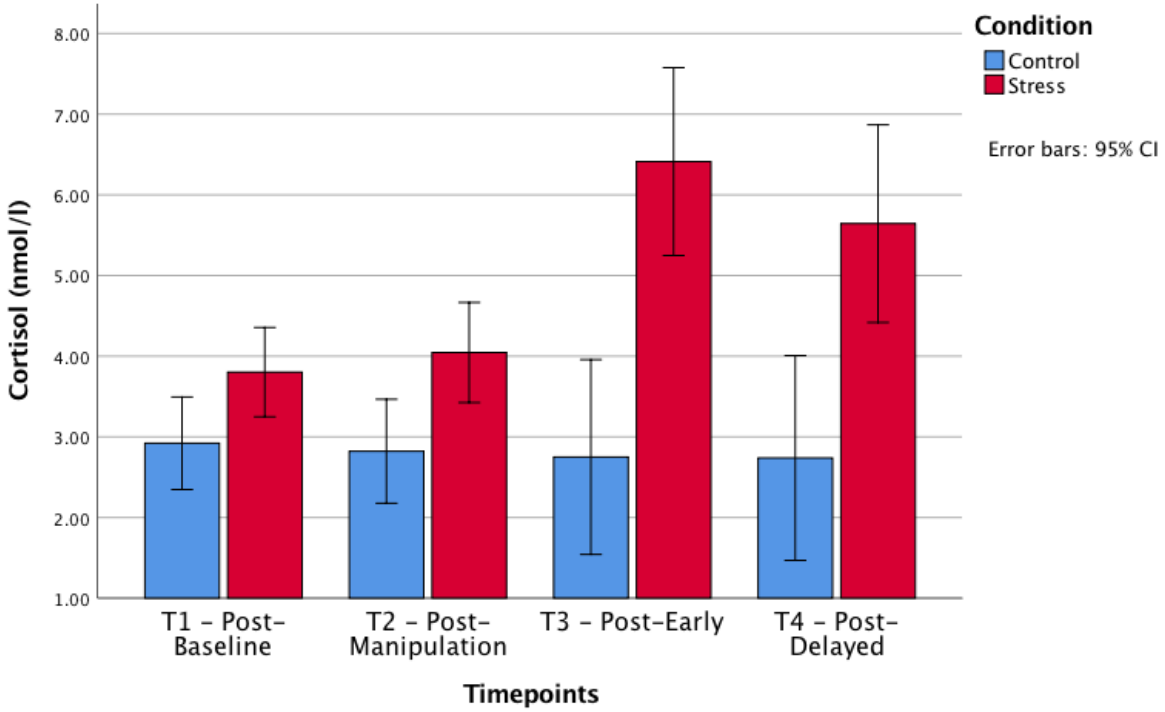


Figure 5.3. Graph demonstrates stress participants Cortisol peaked 20-minutes post-stress (T3) before beginning to recover. However, controls Cortisol levels steadily decreased.

Table 5.2 *Mean (SD) values of salivary Alpha Amylase (sAA – U/ml) and salivary Cortisol (nmol/l) by participants at four time-points.*

			Alpha Amylase (U/ml)*	Cortisol (nmol/l)^
	Condition	*n*	Mean *(SD)*	Mean *(SD)*
Time-point 1	Control	27	119.1 *(51.22)*	2.92 *(1.33)*
	Stress	29	110.97 *(62.38)*	3.8 *(1.62)*
Time-point 2	Control	27	164.65 *(98.23)*	2.82 *(1.27)*
	Stress	29	162.02 *(106.66)*	4.05 *(1.97)*
Time-point 3	Control	27	132.55 *(79.23)*	2.75 *(1.45)*
	Stress	29	130.85 *(70.59)*	6.41 *(4.11)*
Time-point 4	Control	27	137.29 *(73.19)*	2.74 *(2.28)*
	Stress	29	121.61 *(64.89)*	5.64 *(4.01)*

* sAA - Units per millilitre ^ Cortisol - nanomoles per litre

5.4.3 ANT-R

5.4.3.1 Measures

The same four measures used in Experiment One (Chapter Four) were examined. These were alerting, validity, orienting and flanker effects.

5.4.3.2 Reliability check

As in Experiment One, the current experiment used a "split" run of the ANT-R. To validate the approach, split-half reliabilities were again calculated from baseline ANT-R data across all cue types for Accuracy and RT. Pearson correlations showed that participants first half baseline performance across cue types (accuracy and RT) significantly correlated with their performance during the second half of their baseline ANT-R (all r's > .7, all p's < .001). Performance on Flanker congruency was similarly correlated (all r's > .28, all p's < .033). Additionally, Pearson's correlations showed that efficiency measures (accuracy / RT; Townsend and Ashby, 1983) were significantly correlated across the pre- and post-tranches (r's > .914, all p's < .001) implying that like Experiment One, global performance was consistent across two iterations, regardless of whether participants completed their second ANT-R in the early or delayed tranche (see Table 5.3).

Table 5.3 *Correlation matrix for Pre- and Post-manipulation performance (Accuracy and RT).*

		Global Accuracy	Global RT
		Post-manipulation	Post-manipulation
Global Accuracy	Pearsons *r*	.928*	
Pre-manipulation	Sig. (2-tailed)	.000	
Global RT	Pearsons *r*		.914*
Pre-manipulation	Sig. (2-tailed)		.000

* Correlation is significant at the 0.001 level

5.4.3.3 Effects Check

Paired samples t-tests examined whether the ANT-R was producing the expected attentional effects. With the exception of alerting benefit accuracy ($t(59) = -1.41$, $p = .163$, $d = .1$), all effects (both Accuracy and RT) were observed to be significant (all p's < .004, all d's > .17), and in the expected direction. Further, although the alerting benefit (accuracy) was not significant, the means indicate that effect was in the expected direction (No Cue $\bar{x}$ accuracy = 89.1%; Double Cue $\bar{x}$ accuracy = 90.17%).

5.4.3.4 ANT-R Performance Data

5.4.3.4.1 Global Effects

Overall accuracy was calculated for each participant and analysed using a 2 (Condition: Stress vs Control) x 2 (ANT-R Tranche: Pre-stress vs Post-stress) x 2 (Stress time-course: Early vs Delayed) x 2 (Gender: Male vs Female) repeated measures ANOVA. There was no significant main effect of Tranche ($p = .342$) and no significant interaction effect of Tranche and Condition ($p = .921$). However, a three-way interaction of Tranche, Condition and Gender approached significance ($F(1,52) = 4.35$, $p = .042$, partial $\eta^2 = .08$). Post-hoc ANOVAs by Gender revealed no significant interaction of Tranche and Condition for males. A non-significant trend was observed for females ($F(1,38) = 3.16$, $p = .084$, partial $\eta^2 = .08$) indicating that whilst control females demonstrated a small improvement to global accuracy in the Post-stress Tranche, females in the stress group deteriorated slightly. There were no other significant effects (all p's > .195). See Table 5.4 below for means and standard deviations.

An identical 2 x 2 x 2 x 2 repeated measures ANOVA conducted for Response Time (RT) showed there was a significant main effect of Tranche ($F(1,52) = 25.58$, $p < .001$, partial $\eta^2 = .33$). A paired samples t-test indicated RT was significantly quicker in the Post-stress ANT-R compared to the Pre-stress ANT-R ($t(59) = 5.39$, $p < .001$, $d = .3$).

There were no other significant effects (all *p*'s > .098). See Table 5.4 for means and standard deviations.

Table 5.4 *Mean (SD) values of global accuracy and RT performance across the pre- and post-manipulation (split by Early and Delayed).*

			Pre-stress		Early		Delayed
	Condition	*n*	Means *(SD)*	*n*	Means *(SD)*		Means *(SD)*
Accuracy *(%)*	Control	29	91.95 (7.35)	15	93.7 (9.86)	14	92.26 (5.69)
	Stress	31	88.24 (10.84)	15	89.91 (9.07)	16	87 (1.24)
	Total	60	90.03 (9.43)	30	91.81 (9.5)	30	89.44 (10.07)
RT *(ms)*	Control	29	572.66 (88.59)	15	562.57 (88.24)	14	533.56 (66.38)
	Stress	31	553.37 (76.72)	15	518.86 (81.23)	16	537 (74.98)
	Total	60	562.7 (82.53)	30	540.72 (86.24)	30	535.93 (69.92)

5.4.3.4.2 Alerting Benefit

To understand if exposure to (or time since) stress or gender influenced alerting benefit, a 2 (Condition: Stress vs Control) x 2 Tranche (Pre- vs Post-) x 2 (Stress time-course: Early vs Delayed) x 2 (Gender: Male vs Female) repeated measures ANOVA was performed. Regarding accuracy, there was no significant main or interaction effects (all *p*'s > .132) indicating that exposure to stress and its time-course, as well as gender exerted no influence on alerting benefit (accuracy).

An identical ANOVA was performed for RT and showed a three-way interaction of Tranche, Condition and Stress time-course that approached significance ($F(1,52) = 3.34$, $p = .073$, partial $\eta^2 = .06$). Planned post-hoc ANOVAs were performed to explore the Tranche and Condition interaction for both early and delayed groups. The interaction was significant for participants in the early group ($F(1,28) = 5.74$, $p = .023$, partial $\eta^2 = .17$), but did not reach significance for the delayed group ($p = .698$). Further paired samples t-tests indicated that performance amongst stress participants during the early period was not significantly different from their baseline ANT-R ($p = .476$). However, control participants exhibited a significantly reduced alerting benefit during the early period

compared to their baseline ANT-R performance ($t(14) = 3.34$, $p = .005$, $d = 1.02$). The results indicate that participants who experienced stress maintained efficient attentional alerting performance, whereas in the absence of stress the benefit was reduced. No other effects in the ANOVA were significant ($p = .107$).

5.4.3.4.3 Validity Effect

As with the alerting benefit, an ANOVA was performed to examine the validity effect. Regarding accuracy, again there were no significant main or interaction effects (all p's > .299) indicating that validity effect accuracy was not impacted by exposure to stress, its time-course or gender.

For RT, the ANOVA demonstrated a significant interaction effect of Tranche, Condition and Gender ($F(1,52) = 6.3$, $p = .015$, partial $\eta^2 = .11$). Planned post-hoc ANOVAs were performed to explore the Tranche and Condition interaction for males and females individually. There was no significant interaction for males ($p = .277$), however, there was a significant interaction for females ($F(1,38) = 8.6$, $p = .006$, partial $\eta^2 = .18$). Further paired samples t-tests indicated that whilst performance amongst females in the stress group remained unchanged between Pre- and Post-stress ANT-R's ($p = .538$), females in the control group demonstrated a significantly greater validity effect in their later ANT-R, when compared to their baseline performance ($t(19) = -3.83$, $p = .001$, $d = .73$). This observation indicates that whilst control females experience greater effects of validity on their second attempt of the ANT-R, this improvement is inhibited amongst females who have experienced stress.

5.4.3.4.4 Orienting Effect

An ANOVA examined the orienting effect (accuracy) and demonstrated no significant main or interaction effects (all p's > .107).

Similarly, the ANOVA revealed no significant main or interaction effects for RT (all *p*'s > .118). The results indicate that exposure to stress and its time-course, as well as gender had no significant impact on orienting.

5.4.3.4.5 Flanker Effect

An ANOVA examined the flanker effect, and observed an interaction that approached significance for Condition, Tranche and Gender ($F(1,52) = 3.34$, $p = .074$, partial $\eta^2 = .06$). However, post-hoc ANOVAs exploring males and females independently found no significant interactions of Condition and Tranche (*p*'s = .335 and .066, respectively). There were no other significant effects (all *p*'s > .358).

For RT, the ANOVA revealed a main effect of Tranche that approached significance ($F(1,52) = 3.861$, p = .055, partial $\eta^2 = .07$). A post hoc paired samples t-test indicated that the flanker effect reduced in magnitude during the later iteration of the ANT-R, compared to baseline ($t(59) = 2.42$, $p = .019$, $d = .19$). There was also a three-way interaction that approached significance for Tranche, Condition and Stress time-course ($F(1,52) = 3.44$, $p = .069$, partial $\eta^2 = .06$). Planned post hoc ANOVAs were performed to explore the Tranche and Condition interaction for early and delayed periods individually. The Tranche and Condition interaction was not significant for participants during the early period ($p = .214$). However, for participants during the delayed period, the difference did reach significance ($F(1,28) = 4.48$, $p = .043$, partial $\eta^2 = .14$). Further post-hoc paired samples t-tests indicated that whilst there was no difference in performance amongst controls across iterations of the ANT-R ($p = .909$), participants who had experienced stress demonstrated a significantly reduced flanker effect during the delayed ANT-R compared to their baseline performance ($t(15) = 3.68$, $p = .002$, $d = .59$).

The data show that efficiency of the alerting and executive control networks differed over the duration of the experiment between stress and control participants. The original hypothesis proposed that participants exposed to stress would see an increased

alerting benefit relative to controls, both in early and delayed periods of measurement. The results show that whilst the alerting benefit for control participants reduced immediately following the control task, participants who experienced the SECPT were able to maintain the alerting benefit they had displayed at baseline. This suggests that exposure to acute stress helps maintain alert attention, when it would normally be expected to deteriorate. A further hypothesis stated that executive control performance would alter following acute stress. Supporting this, the results show that stress participants experienced a reduced flanker effect 20-35 minutes after the SECPT. Closer examination reveals that whilst control participants demonstrated speeding of responses to both Congruent and Incongruent trials, participants who had experienced acute stress showed a reduced effect of Incongruent trials, and virtually no difference on trials with Congruent flankers. Finally, the results indicate that exposure to stress altered validity performance, but only amongst female participants. Contrary to the original hypothesis which stated that the cue validity effect should enlarge following stress, females who experienced the SECPT exhibited no difference to the magnitude of their validity effect, irrespective of whether they were tested in the early or delayed period. Conversely, the cue validity effect did increase amongst female controls participants post-manipulation, with mean RTs indicating that this was due to a lack of improvement on invalidly cued trials. In the absence of acute stress performance flattened, however with stress, participants exhibited improved orienting on invalidly cued trials.

5.4.4 Physiological Influence – ANT-R Regressions.

To investigate how physiological reactivity to stress might influence ANT-R performance, a series of regressions were performed.

5.4.4.1 Data sanitisation

Due to incomplete or unsuitable physiological data (for details, see section 5.3.1.1) four participants were excluded from this portion of analysis.

5.4.4.2 Predictors

As per Experiment One (Chapter Four) Gender, OSPAN and Task-focused coping (CITS-S) were included in each regression. For baseline tranche regressions, Condition, Trait Anxiety (STAI) and basal physiology was included (T1 sAA and Cortisol). For early and delayed tranche regressions, State Anxiety (SSAI) was again included as a proxy for Condition. Similarly, aggregated Intolerance of Uncertainty (IUS-12) was included in place of STAI to prevent issues of multicollinearity with physiology measures and SSAI. T2 sAA / Cortisol was included for Early regressions, whilst T3 sAA / Cortisol was included for Delayed regressions. In line with Experiment One, the biomarker measurements used were absolute values (as opposed to differences scores). Once again, multiple regressions using the difference score values were computed but were not materially different from the absolute values, therefore only absolute values are reported.

5.4.4.3 Results

Baseline: Basal Cortisol approached significance for predicting the orienting effect (accuracy) ($p = .054, \beta = .27$), indicating that the effect was smaller amongst participants with higher levels of Cortisol. However, physiology did not predict any other measure (all p's > .201). Regarding accuracy, OSPAN score significantly predicted the orienting effect ($p = .018, \beta = -.31$) indicating those with higher OSPAN scores exhibited larger differences (in accuracy) between trials with double cues and valid cues compared to people with lower OSPAN scores. Regarding RT, OSPAN score significantly predicted alerting benefit RT ($p = .034, \beta = .3$), implying that higher working memory resulted in a larger difference in RT between trials with no cues and those with a double cue. OSPAN also weakly predicted orienting effect (RT) performance ($p = .056, \beta = -.27$) suggesting that higher working memory resulted in smaller differences between double cue and valid cue trials (see Tables 5.5 and 5.6).

Early: None of the factors entered into the regression, including physiology, significantly predicted any performance measure during the early ANT-R (all p's > .070)

Delayed: T3 Cortisol did weakly predict the flanker effect, albeit not quite at a significant level (RT) (p = .064, β = .51) indicating that those with higher levels of Cortisol following the manipulation also tended to experience larger flanker effects during the Delayed period, when the HPA-Axis was expected to peak following exposure to stress. Further regressions exploring the measures that comprise this difference score (flanker congruent/incongruent trials) indicated that the effect was more likely the product of longer RT on Incongruent trials (p = .068, β = .51), than any change on Congruent Trials (p = .260, β = .33). Neither sAA nor Cortisol predicted any other effects (all p's > .093). Furthermore, accuracy was not predicted by any factor entered into the regression, however IUS (aggregated) did significantly predict validity effect (RT) (p = .035, β = .433). This suggests that participants who rated themselves as significantly more intolerant of uncertainty (higher anxiety) demonstrated a larger difference between Invalid and Valid cue performance than those with lower IUS scores. There were no other effects (all p's > .068 – see Tables 5.5 and 5.6).

The results show that stress-linked physiology shares a weak relationship with attentional performance. Smaller orienting effects were predicted by higher levels of basal Cortisol; however, this was prior to any experimental stressor. Conversely, higher levels of Cortisol during the delayed period, when levels are expected to peak following stress, was able to (weakly) predict larger flanker effects due to poorer performance on Incongruent trials. Although only a trend, it is interesting that the result directly contradicts the behavioural data and conflicts with our original hypothesis that any behavioural change should share a positive relationship to any change induced by stress physiology (see ANOVA results for Flanker Effect – 5.4.3.4.5). Increased Intolerance of Uncertainty, a trait related to stress susceptibility did predict an increased validity effect during the delayed period of testing. However, the result again contradicts the behavioural

data which showed that exposure to stress resulted in no change to validity performance, whilst non-stressed females did exhibit an enlarged validity effect. Working memory appeared to predict alerting attention, with higher OSPAN scores reflecting a larger alerting benefit at baseline. However, whilst the regressions indicated that OSPAN also predicted the orienting effect for both accuracy and RT, this was most probably the result of a participant speed-accuracy trade-off.

Table 5.5 *Regression table showing predictors at each tranche (baseline / early / delayed) for each of the four attentional effects (accuracy).*

Accuracy	Baseline			Early			Delayed		
	Beta	*p*	Predictor	Beta	*p*	Predictor	Beta	*p*	Predictor
Alerting Benefit	-0.19	0.246	Condition	-0.23	0.300	Gender	-0.30	0.167	Gender
	0.00	0.996	Gender	0.20	0.378	OSPAN	0.04	0.836	OSPAN
	0.22	0.104	OSPAN	-0.02	0.931	IUS Agg	-0.36	0.094	IUS Agg
	-0.12	0.391	STAI	0.19	0.400	SSAI	0.23	0.405	SSAI
	0.02	0.885	Task Coping	-0.26	0.286	Task Coping	0.04	0.857	Task Coping
	0.19	0.201	T1 sAA	-0.14	0.526	T2 sAA	-0.30	0.183	T3 sAA
	-0.08	0.569	T1 Cortisol	0.01	0.975	T2 Cortisol	-0.09	0.747	T3 Cortisol
Validity Effect	-0.23	0.180	Condition	-0.07	0.744	Gender	0.25	0.269	Gender
	0.15	0.330	Gender	0.07	0.739	OSPAN	0.20	0.384	OSPAN
	0.01	0.957	OSPAN	-0.09	0.650	IUS Agg	0.28	0.208	IUS Agg
	0.00	0.987	STAI	-0.38	0.070	SSAI	-0.50	0.094	SSAI
	0.09	0.575	Task Coping	0.16	0.453	Task Coping	0.34	0.175	Task Coping
	-0.05	0.732	T1 sAA	0.24	0.252	T2 sAA	0.04	0.857	T3 sAA
	0.15	0.331	T1 Cortisol	0.18	0.363	T2 Cortisol	0.12	0.677	T3 Cortisol
Orienting Effect	0.18	0.242	Condition	0.24	0.284	Gender	0.01	0.958	Gender
	-0.04	0.774	Gender	-0.24	0.283	OSPAN	0.17	0.446	OSPAN
	-0.31	0.018 *	OSPAN	0.08	0.733	IUS Agg	0.25	0.256	IUS Agg
	0.06	0.658	STAI	-0.15	0.491	SSAI	-0.25	0.384	SSAI
	-0.23	0.141	Task Coping	0.23	0.346	Task Coping	-0.33	0.188	Task Coping
	0.06	0.686	T1 sAA	-0.16	0.470	T2 sAA	0.27	0.243	T3 sAA
	0.27	0.054 *	T1 Cortisol	0.16	0.449	T2 Cortisol	0.42	0.150	T3 Cortisol
Flanker Effect	-0.29	0.096	Condition	-0.14	0.549	Gender	0.20	0.355	Gender
	0.05	0.720	Gender	0.09	0.683	OSPAN	-0.09	0.676	OSPAN
	-0.08	0.589	OSPAN	-0.06	0.789	IUS Agg	0.24	0.264	IUS Agg
	-0.09	0.534	STAI	0.01	0.977	SSAI	-0.30	0.294	SSAI
	0.09	0.579	Task Coping	0.19	0.447	Task Coping	-0.27	0.273	Task Coping
	-0.04	0.770	T1 sAA	0.21	0.357	T2 sAA	-0.13	0.566	T3 sAA
	0.06	0.706	T1 Cortisol	0.09	0.687	T2 Cortisol	0.16	0.577	T3 Cortisol

Table 5.6 *Regression table showing predictors at each tranche (baseline / early / delayed) for each of the four attentional effects (RT).*

RT	Baseline			Early			Delayed		
	Beta	*p*	Predictor	Beta	*p*	Predictor	Beta	*p*	Predictor
Alerting Benefit	-0.05	0.751	Condition	-0.04	0.870	Gender	-0.10	0.635	Gender
	0.05	0.717	Gender	0.20	0.348	OSPAN	0.40	0.068	OSPAN
	0.30	0.034 *	OSPAN	-0.22	0.315	IUS Agg	-0.04	0.858	IUS Agg
	0.03	0.854	STAI	0.36	0.102	SSAI	0.36	0.183	SSAI
	0.00	0.992	Task Coping	0.20	0.381	Task Coping	-0.31	0.186	Task Coping
	0.01	0.964	T1 sAA	0.04	0.842	T2 sAA	-0.04	0.867	T3 sAA
	-0.15	0.326	T1 Cortisol	-0.04	0.858	T2 Cortisol	-0.14	0.616	T3 Cortisol
Validity Effect	0.12	0.473	Condition	0.00	0.995	Gender	0.34	0.093	Gender
	0.05	0.727	Gender	0.03	0.902	OSPAN	-0.09	0.645	OSPAN
	-0.18	0.214	OSPAN	-0.10	0.675	IUS Agg	0.43	0.035 *	IUS Agg
	0.06	0.710	STAI	0.18	0.459	SSAI	-0.27	0.292	SSAI
	-0.08	0.639	Task Coping	-0.15	0.546	Task Coping	0.14	0.522	Task Coping
	-0.11	0.470	T1 sAA	-0.01	0.975	T2 sAA	-0.35	0.093	T3 sAA
	-0.09	0.539	T1 Cortisol	0.14	0.560	T2 Cortisol	-0.20	0.434	T3 Cortisol
Orienting Effect	0.24	0.154	Condition	-0.13	0.581	Gender	0.14	0.528	Gender
	-0.07	0.637	Gender	-0.14	0.555	OSPAN	-0.31	0.191	OSPAN
	-0.27	0.056 *	OSPAN	0.15	0.515	IUS Agg	0.28	0.211	IUS Agg
	0.11	0.442	STAI	-0.08	0.739	SSAI	-0.24	0.416	SSAI
	-0.14	0.391	Task Coping	-0.07	0.793	Task Coping	0.23	0.374	Task Coping
	0.05	0.724	T1 sAA	-0.13	0.596	T2 sAA	-0.24	0.313	T3 sAA
	-0.10	0.484	T1 Cortisol	0.13	0.575	T2 Cortisol	-0.06	0.847	T3 Cortisol
Flanker Effect	-0.17	0.327	Condition	-0.25	0.263	Gender	0.07	0.744	Gender
	-0.08	0.614	Gender	-0.28	0.211	OSPAN	0.37	0.089	OSPAN
	-0.05	0.754	OSPAN	-0.25	0.262	IUS Agg	0.32	0.122	IUS Agg
	0.02	0.892	STAI	0.03	0.875	SSAI	-0.34	0.205	SSAI
	0.20	0.244	Task Coping	0.16	0.499	Task Coping	-0.19	0.420	Task Coping
	0.02	0.890	T1 sAA	0.21	0.352	T2 sAA	-0.18	0.397	T3 sAA
	0.11	0.475	T1 Cortisol	-0.07	0.749	T2 Cortisol	0.51	0.064 *	T3 Cortisol

5.5 Discussion

Experiment 2 examined how attentional network performance was impacted by exposure to acute stress. Further, Cortisol, the preferred biomarker of stress induction is known to follow a diurnal with levels peaking shortly after awakening and steadily decreasing throughout the day (Nater et al., 2007; Smyth et al., 1997). Therefore, a second aim of the study was to examine attentional performance following exposure to stress in the afternoon, when basal Cortisol is low. Finally, the study looked to examine whether higher production of stress biomarkers (sAA and Cortisol), regarded in the literature as evidence of a stressed state, directly influenced attentional performance. Participants completed baseline attentional performance measures using the ANT-R before they were exposed to either the Socially Evaluative Cold Pressor Task (SECPT) or a warm water control. Attentional performance was then measured in one of two periods; immediately following the SECPT or control task reflecting the expected peak of SNS activity, or in a delayed period when HPA-Axis activity was expected to peak.

5.5.1 Stress induction

Effective stress induction was examined using both self-report measures and physiological data. In line with Hypothesis One participants who were exposed to the SECPT reported that the experience was significantly more stressful, demanding and required more effort than participants who had experienced the equivalent warm water control task. Furthermore, as predicted, stressed participants rated their own task performance as poorer than controls, reported higher levels of state anxiety and also engaged in greater levels of both task-focused and emotion-focused coping.

Additionally, physiological data showed that Cortisol level was significantly elevated at T3 (anticipated peak) and T4 (commencement of recovery) in those who had experienced the SECPT. Control participants however, exhibited no significant changes, thus supporting Hypothesis 2.

Alpha Amylase levels were elevated for all participants, regardless of condition immediately following the SECPT or control task (T2). This could indicate that participants in the control group experienced anticipatory stress and thus match the results reported in Experiment One (Bosch et al., 1996; Robinson et al., 2013). However, as noted in Experiment One, the results could also have resulted from the enhanced sensitivity of sAA as a measure and the influence of heightened PNS activity, stemming from the "relaxation" possibly induced in control participants as they immersed their hand in warm water. Nevertheless, participants in the control group only exhibited this increase at T2 then returned to baseline levels, whilst participants in the stress group maintained elevated sAA levels for the duration of the study, meaning different sAA profile were observable depending on a participant's condition. This replicates the finding of Experiment One and, whilst it reveals a non-typical sAA response for controls, the results offer strong support for the effective induction of stress in the present study.

5.5.2 ANT-R performance

Attentional performance was measured at two of three time-points, using the ANT-R. Participants completed a baseline ANT-R (four blocks) before completing one post-manipulation ANT-R either immediately (early – two blocks) or delayed (two blocks). This followed the split-half design utilised in Experiment One and previously employed by Greene et al. (2008). Split-half reliabilities showed excellent correlations across all cue types and significant correlations across flanker congruency, thereby providing strong support for the use of this approach. Further, whilst global RT showed an overall speeding of responses, irrespective of group, global accuracy was stable across the course of the experiment.

5.5.2.1 Stress and the ANT-R

Regarding accuracy, attentional performance did not change on any of the four measures following exposure to acute stress. This was in accordance with expectations for

the alerting benefit and validity and orienting effects as cue type was not anticipated to interact with target accuracy. However, stress was anticipated to influence both accuracy and RT with regard to the flanker effect. Previous studies have reported that exposure to stress leads to a narrowing of attention (Chajut & Algom, 2003; van Steenbergen et al., 2011) whilst others have suggested that attention might broaden (Skosnik et al., 2000) and impair key components such as decision making and inhibition (Alomari et al., 2015; Elling et al., 2011). In the present study, if stress facilitated a narrowing of attention, participants accuracy should be improved on incongruent flanker trials (compared to controls) as they are influenced less by distracting (incongruent) flankers, thus reducing the magnitude of the flanker effect. Furthermore, with less processing of visual information required, RT would also be expected to reduce. However, if attention was broadened, or decision making impaired, accuracy should be poorer as incongruent flankers interfere with decision making, increasing the magnitude of the flanker effect for both accuracy and RT.

The results indicate that for accuracy, the flanker effect was not different between stress and controls, however there was a significant difference regarding RT. The data show that when compared to their baseline, participants who had undertaken the SECPT demonstrated a significantly reduced flanker effect (131.35 *ms* versus 110.95 *ms* respectively). By comparison, participants in the control group demonstrated a non-significant reduction from their baseline to their post-manipulation measurement (141.22 *ms* versus 124.33 *ms* respectively) (see Table 5.7). This effect was only present in those who had completed their second ANT-R in the delayed period and indicates a narrowing of attention. However, examination of the means indicates that control participants performance speeded for both flanker incongruent and congruent trials (47.54 *ms* and 30.65 *ms* respectively), indicative of a practice effect. Conversely, for participants in the stress group, such improvement was absent for congruent trials (5.18 *ms*) and reduced for trials with incongruent flankers (25.58 *ms*). Although the improvement on incongruent

flankers might imply a narrowing of attention, the improvement was smaller than that exhibited by controls. Instead the main difference was observed on congruent trials which would indicate neither a narrowing nor a broadening of attention as hypothesised. Instead, the current results imply that the reduced flanker effect actually stems from the suppression of a practice effect that was present amongst controls. Previous studies have reported some impaired learning following stress, often related to memory or spatial working memory (maze wayfinding) (Holscher, 1999; Schwabe & Wolf, 2010). However, reports of suppressed attentional task learning are lacking.

Table 5.7 *Mean (SD) RT of trials (congruency) used to calculate Flanker Effect for both stress and controls, across baseline and delayed tranches.*

	Condition	*n*		Means *(SD)*	Flanker Effect	Flanker Improvement
Baseline	Control	29	Incongruent	643.27 (111.14)		
			Congruent	502.05 (72.22)	141.22 *ms*	
	Stress	31	Incongruent	619.05 (94.15)		
			Congruent	487.7 (61.86)	131.35 *ms*	
Delayed	Control	14	Incongruent	595.73 (81.78)		47.54 *ms*
			Congruent	471.4 (58.42)	124.33 *ms*	30.65 *ms*
	Stress	16	Incongruent	593.47 (86.22)		25.58 *ms*
			Congruent	482.52 (67.08)	110.95 *ms*	**5.18 *ms***

***Bold indicates the trial type thought to be driving effect**

Exposure to acute stress did alter other aspects of participants attentional performance, with the magnitude of the alerting benefit showing group differences. Participants who experienced the warm water control task exhibited a significantly reduced alerting benefit (19.90 *ms*) immediately following the task compared to their baseline performance (38.98 *ms*). Conversely, participants who experienced the SECPT demonstrated a non-significant increase to their alerting benefit (43.14 *ms*) when compared to baseline (33.94 *ms*). Closer inspection of the means used to compute the alerting benefit reveal that this difference was a result of control participants failing to show any improvement to "Double Cue" following the control task (see Table 5.8 for means). The

results offer support for Hypothesis 3, which predicted that exposure to stress would result in increased alerting performance relative to control participants due to a hypervigilance. Previously vigilant attention has been shown to be maintained under conditions of stress (e.g. aircraft noise - Helton, Matthews, & Warm, 2009) or initiate a move toward a state of heightened vigilance (Henckens et al., 2012; Richards et al., 2014; van Marle et al., 2009; Weymar et al., 2012). In the present study, exposure to the SECPT permitted participants to maintain a vigilant state immediately following the stressor which resulted in improved performance across trials with no cues and with double cues. However, in the absence of stress, control participants failed to gain any advantage from the double cue that alerted them to an imminent target presentation.

The change to alerting was only exhibited in the period immediately following exposure to stress and not in the delayed period. Previous studies have demonstrated heightened vigilance in both the immediate aftermath of stress (Olofsson et al., 2008; van Marle et al., 2009) and the delayed period (Roelofs et al., 2007; Veer et al., 2011). Further, studies have shown how such hypervigilance is linked to physiological activation prevalent during these periods. Heightened vigilance has been associated with anxiety and high SNS activity / low parasympathetic activity (Kinnealey & Fuiek, 1999; Thayer & Brosschot, 2005) as well as with Cortisol (Akinola & Mendes, 2012; Henckens et al., 2012; Veer et al., 2011; Weymar et al., 2012). However, several of those latter studies may not have correctly or fully accounted for the responsibility of the SNS reaction. To illustrate, in their study, Akinola and Mendes (2012) reported that stress-induced Cortisol enhanced vigilance in police officers completing a "shoot/don't shoot" exercise. However, the 20-minute exercise was carried out immediately following the stressor, followed by the collection of Cortisol samples. This design would instead implicate activation of the SNS, not the HPA-Axis and Cortisol, which was likely peaking as the exercise reached its conclusion. Similarly, in their study, Veer et al. (2011) waited 60 minutes before testing participants. However testing was conducted using an fMRI methodology possibly

introducing additional stress due to the environment (noise / confined space etc.- Hommel, Fischer, Colzato, van den Wildenberg, & Cellini, 2012; Joëls, Pu, Wiegert, Oitzl, & Krugers, 2006). Other results might have been due to emotional stress (Weymar et al., 2012) or the use of pharmacological interventions (Henckens et al., 2012). It is possible that those changes only occurred following acute sympathetic activation, as was reported by Elzinga and Roelofs (2005) when examining working memory. This offers a partial explanation for the absence of any effect during the delayed period amongst stressed participants. Alternatively, the observation could have resulted as a consequence of the hypervigilance itself. If participants have maintained a state of watchful vigilance in the immediate period (regardless of completing the attention or relaxation task), increased levels of mental fatigue from maintaining that level could result in a subsequent reduction (vigilance decrement) returning them to control levels alertness (N. H. Mackworth, 1948; Marcora et al., 2009).

Table 5.8 *Mean (SD) RT of trials (cues) used to calculate Alerting Benefit for both stress and controls, across baseline and early tranches.*

	Condition	*n*		Means *(SD)*	Alerting Benefit	Cue improvement
Baseline	Control	29	No Cue	615.08 (99.39)		
			Double Cue	576.1 (91.63)	38.98 *ms*	
	Stress	31	No Cue	594.74 (90.06)		
			Double Cue	560.8 (79.14)	33.94 *ms*	
Early	Control	15	No Cue	596.24 (88.4)		18.84 *ms*
			Double Cue	576.34 (92.88)	19.9 *ms*	**-0.24 *ms***
	Stress	15	No Cue	568.82 (96.73)		25.92 *ms*
			Double Cue	525.68 (87.46)	43.14 *ms*	35.12 *ms*

Exposure to acute stress was also anticipated to reduce the validity effect post-stress, relative to controls, as hypervigilance led to speeded RTs on Invalidly cued trials (H4). The data partially supported this hypothesis, as females in the control group demonstrated a significantly increased validity effect post-stress (69.4 *ms* to 94.66 *ms*). Conversely, females who experienced the SECPT exhibited a non-significant reduction to

their validity effect (88.81 *ms* to 83.85 *ms*; see Table 5.9). Further, this difference was present independent of whether participants completed the attention task immediately or after a 20-minute delay. As predicted, whilst both stress and controls observed improved Valid cue performance, Invalid performance was maintained for controls, but was significantly improved (33.64 ms) for females after the SECPT thus supporting previous work by (Q. Feng et al., 2011; Merritt et al., 2007) . Interestingly, male participants demonstrated no such differences.

Table 5.9 *Mean (SD) RT of trials (cues) used to calculate Validity Effect for both stress and controls (Females), across baseline and post-stress tranches.*

Females	Condition	*n*		Means *(SD)*	Validity Effect	Cue Improvement
Pre-	Control	20	Invalid	622.7 (91.56)		
			Valid	553.3 (86.74)	69.4 *ms*	
	Stress	20	Invalid	608.21 (94.42)		
			Valid	519.4 (73.44)	88.81 *ms*	
Post-	Control	20	Invalid	621.76 (98.63)		**0.94 *ms***
			Valid	527.1 (79.37)	94.66 *ms*	26.2 *ms*
	Stress	20	Invalid	574.57 (85.92)		33.64 *ms*
			Valid	490.72 (79.73)	83.85 *ms*	28.68 *ms*

Finally, regarding attentional performance it was hypothesised that exposure to stress would lead to a reduced orienting effect (H5), similar to that seen with the validity effect above. However, no significant differences were observed between stress and control performance. This is surprising given the apparent presence of hypervigilance that appears to have influenced the alerting benefit and validity effect. However, the magnitude of difference for any orienting effect was always likely to be smaller than for validity, given the difference between the significant 'cost' of an invalid cue compared to the small 'benefit' of a double cue. The difference for the validity effect (observed above) equates to 30.22 ms (4.96 ms improvement in stressed females vs. 25.26 ms deterioration

in controls). Any difference for orienting resulting from hypervigilance would likely be smaller and therefore may have failed to reach significance.

A further aim of the study was to investigate the influence of stress-induced physiological change on attentional performance (H7). A series of regressions indicated little evidence for stress-induced physiology impacting attentional performance. However, higher Cortisol level at baseline was weakly associated with a reducing orienting effect. Paradoxically, this would support our unconfirmed hypothesis above (H5), that stress would reduce the orienting effect. However, this was prior to stress exposure, and furthermore was absent at the post-stress time points (Early / Delayed) when Cortisol would be expected to be higher (or peak amongst stress participants). A further relationship was observed during the delayed period, whereby participants with higher levels of Cortisol were weakly correlated with an enlarged flanker effect. This result directly contradicts the behavioural data that showed participants exposed to the SECPT demonstrated a smaller flanker effect, relative to controls. Previously, researchers have separated samples into Cortisol "responders" and "non-responders" (or high / low responders) and linked stress physiology to changes in attention (Bohnen et al., 1990), memory (Domes et al., 2004) and working memory (Al'Absi, Hugdahl, & Lovallo, 2002). In the present study it appears that stress-induced physiology has little direct influence on attentional performance (in the afternoon), although such a finding is not unique. In their study, Alomari et al. (2015) examined high and low responders and found no association between Cortisol and neural processing on an emotion task. One explanation might be that previous work has assumed too much importance of the physiological reaction, and not adequately accounted for other factors, such as the subjective appraisal of participants response to stress. Whilst physiology might be useful in identifying stressed individuals, how participants appraise any post-stress tasks, and their ability to cope with and succeed at those tasks, could be more important to performance.

5.5.2.2 Other factors and the ANT-R

Similar to Experiment One, working memory (OSPAN) predicted aspects of attentional performance. However, Experiment One reported that individuals with higher working capacity exhibited reduced interference to executive control, supporting earlier work by Redick and Engle (2006). In contrast, in Experiment Two participants with higher working memory demonstrated a larger alerting benefit. One explanation for this might be that individuals with higher working memory were able to maintain engagement with the task and extract a larger benefit from the alerting (double) cue, compared to those with lower working memory. There was also weak evidence for a relationship between OSPAN and orienting performance, however this appeared to be the result of a speed-accuracy trade-off.

Aggregated intolerance of uncertainty was the only other factor to have shared a significant relationship with attentional performance, namely the validity effect. Intolerance of uncertainty is known to share a relationship with trait anxiety and therefore the susceptibility to become stressed. Interestingly, those rating themselves as highly intolerant were shown to experience a larger validity effect. This is in contrast to those who actually experienced stress and were shown to exhibit a reduced validity effect due to heightened vigilance. It appears that worry, or fear of getting stressed leads to poorer alerting, but experiencing stress actually improves it.

5.5.3 Limitations

The present experiment addressed several issues identified in Experiment One. Firstly, the confounding effect of Time of Day was resolved by limiting testing of participants to the afternoon, thereby reducing the potential for results to be influenced by the Cortisol Awakening Response (CAR). This practice has been adopted across stress literature given the reported associations between elevated Cortisol and cognition, as well as increased inter-individual variance in the morning, whereas levels tend to be both lower

and more stable in the afternoon (e.g. Sato, Takenaka, & Kawahara, 2012; Walser, Fischer, Goschke, Kirschbaum, & Plessow, 2013). However, the results in the present study indicate a distinct lack of any physiological influence on cognitive performance.

As noted in Experiment One, the use of split-halves to permit early and delayed measurement of attention resulted in a loss of power, as a reduced number of trials were used to calculate the difference scores. It might be argued that further reducing that number by requiring participants to complete only one post-manipulation ANT-R (two blocks) compounds this issue. However, as analyses focused on discrete post-manipulation periods (early or delayed), the experiment offers no less power than Experiment One. Nevertheless, as stated in Experiment One, future work should look to further investigate the effects reported here with a more specified task, employing a greater number of trials to improve statistical power.

Following the atypical sAA response of control participants in Experiment One, the methodology was adjusted slightly so that control participants were made aware of their condition prior to immersing their hand in the water. Despite this, participants in the present study again demonstrated the unexpected increase in sAA level at T2. Evidently, warning participants in the minutes before immersing their hand was not sufficient to dampen any apparent anticipatory stress experienced by controls. This increases the possibility that the higher levels of sAA observed in both Experiments One and Two were a result of measuring an overly-sensitive biomarker (that potentially changed due to PNS as well as SNS activity), rather than just anticipatory stress. Therefore, future experiments should not only explain to control participants the nature of their condition long before they encounter the (control) task, but should also look to other non-invasive measures of SNS activity such as heart rate measurement. This would provide further clarity as to whether the participants stress response (i.e. increased SNS activity) is responsible for any change, rather than a confound of greater SNS reactions in the experimental group coupled with greater PNS activity in the control group.

The present experiment, as with Experiment One, employed a mixed gender sample. Previous work has expounded the contrasting impact of stress on males and females (Almela et al., 2011; Kirschbaum et al., 1999; Verma et al., 2011), whilst gender differences have also been reported for attentional performance (Knight & Mather, 2013; Merritt et al., 2007). Future work should endeavour to sample males and females separately, with sufficient power in order to clearly delineate gender differences following acute stress.

5.5.4 Conclusion

The intention of the present study was to investigate the impact of stress exposure, and its resulting physiology on attentional network performance in the afternoon. Although providing little evidence for the direct influence of physiology on attentional performance, the data show that exposure to acute psychosocial stress leads to a state of heightened vigilance, which improves one's ability to respond quickly following a cue. Similarly, such hypervigilance also facilitated more efficient reorienting of attention, relative to controls, but only amongst female participants. Finally, whilst executive control was also impacted by stress this did not result in a narrowing or broadening of attention, nor from impaired decision making as often reported. Instead, it appears that exposure to acute stress suppressed a practice effect, present amongst controls, that would have permitted continued performance improvements on congruent flanker trials.

6 Experiment Three

6.1 Chapter Overview

Data from Experiment Two provided evidence for the influence of stress exposure on attentional performance as measured by the ANT-R. In accordance with existing literature, the experiment was performed in the afternoon to minimise the likelihood of the Cortisol Awakening Response (CAR) confounding the data. However, such an approach overlooks the possibility of experiencing stress in the morning, and also lacks direct application towards those who are employed in shift-work or night work, whereby the CAR will be experienced at different times of the day, often in magnitudes different to those in the morning. Therefore, the purpose of the present study was to replicate Experiment Two with a morning sample in order to examine the feasibility of conducting morning stress studies. Although the attentional performance was expected to take place outside of the typical CAR window, various measures were collected that would allow any influence of the CAR to be accounted for..

6.2 Introduction

It has long been understood that exposure to stress has the potential to induce both behavioural and physiological changes on an individual (Bourne Jr & Yaroush, 2003). Examination of the physiological manifestation of stress has centered on two pathways; the Sympathetic Nervous System, active during the period immediately following stress exposure; and the Hypothalamic Pituitary Adrenal (HPA) Axis, active in the delayed aftermath of exposure.

As early as the 1980s, Cortisol was identified as a dependable indicator of the Hypothalamic Pituitary Adrenal Axis, due to its ease of collection and reliable analysis (Kirschbaum & Hellhammer, 1989). As such Cortisol measurement has been conspicuous

in stress research ever since (Akinola & Mendes, 2012; Roelofs et al., 2007; Shields et al., 2016; Vedhara et al., 2000). It is also recognised that Cortisol production follows a diurnal cycle, reaching a daily peak during the last hours of sleep before it steadily decreases over the course of the day (Tsigos & Chrousos, 2002). However, it has also been extensively reported that during the 20-60 minutes following awakening, in the absence of any stressor, that Cortisol levels increase sharply. This reaction is termed the Cortisol Awakening Response (CAR; Fries, Dettenborn, & Kirschbaum, 2009; Kudielka, Federenko, Hellhammer, & Wüst, 2006).

The CAR is characterized by blood Cortisol levels increasing by up to 100 % (Kudielka et al., 2012; Pruessner et al., 1997). It is relatively stable within individuals and observable in approximately 75 % of adults (Wüst et al., 2000). Many studies have drawn a relationship between increased Cortisol level and the effects of stress on cognition (Elling et al., 2011; Hidalgo et al., 2014; Putman et al., 2010). For this reason, many stress researchers have limited their studies to the afternoon in an attempt to both avoid the sharp rise and decline of Cortisol normally observed after awakening, and collect Cortisol when basal levels are lower and more stable, thus minimising the risk of confounding errors due to distorted basal Cortisol level (Sänger et al., 2014; van Marle et al., 2009; Zandara et al., 2016).

Afternoon designs are, of course, most applicable to stress experienced at that time of the day, i.e. when Cortisol levels are expected to be more stable (van Marle et al., 2009). However, unfortunately, such designs also miss the opportunity to understand how stress might be experienced differently – and thus lead to different cognitive changes – at other periods throughout the day. This is an important point, for two reasons. The first is that the CAR itself is distinct from the circadian diurnal cycle of the HPA Axis and instead relates specifically to awakening (Vargas & Lopez-Duran, 2017; Wilhelm, Born, Kudielka, Schlotz, & Wüst, 2007). Thus, applying this understanding to anyone who works shift patterns or nights, such as those in the maritime and aviation industries, or individuals who

are late-risers (such as university students who are often sampled in these studies) might not be appropriate. Although research has shown the CAR may be less pronounced when experienced at alternative times of the day, it is still able to demonstrate a significant increase (Bostock & Steptoe, 2013). Therefore, there is still the possibility that the CAR may impact on cognition at those times that are often selected for testing. The second reason is that basal levels of Cortisol in the morning, even outside of the CAR window are likely to be both higher, and more unstable than in the afternoon. As stress can occur at any time of the day, it is important to understand whether performance is altered in the same or a different manner when experienced in the morning (with higher/unstable levels) than in the afternoon (lower/stable levels).

For this reason, the present study explores the impact of acute stress on attention during a morning test session. The design will match that of Experiment Two. Participants will complete a baseline ANT-R before undertaking either an acute psychosocial stressor (SECPT) or control task, after which they will complete a second ANT-R. This will be completed in either the immediate period following stress (0-15 minutes), a period linked to Sympathetic Nervous System activation, or in a delayed period (20-35 minutes) when HPA-Axis activity is expected to peak. Although testing will take place outside of any expected CAR (attentional performance tested at least 60 minutes after participant arrival), to account for the possibility of a CAR, the length of time participants have been awake prior to attending the session will be recorded. Additionally, participants will also complete a sleepiness rating (Karolinska Sleepiness Scale) to provide a measure of tiredness. This will be used to understand whether tiredness, related to the CAR and proximity to waking exerts any influence on attentional performance.

6.2.1 Hypotheses

The hypotheses were similar to those of Experiments One and Two:

1) Exposure to the SECPT will result in greater levels of self-reported stress than those participants subjected to a warm water control task and require significantly higher levels of coping, particularly task-focused coping.

2) Exposure to the SECPT will produce the typical physiological response with regard to the SNS (higher levels amongst stress, peaking immediately following SECPT) and the HPA-Axis (higher levels, peaking in the delayed period following SECPT).

3) Participants in the stress group will demonstrate enhanced alerting (RT), relative to controls, at both the early and delayed periods.

4) Participants in the stress group will demonstrate reduced validity effects (RT), relative to controls.

5) Participants in the stress group will demonstrate reduced orienting effects (RT), relative to controls.

6) The flanker effect of participants in the stress group will differ from controls following stress. If stress results in narrowed attention, participants will demonstrate a reduced flanker effect (accuracy and RT). However, if stress instead impairs decision making, the magnitude of the flanker effect will be enlarged (accuracy and RT).

7) Higher levels of physiological biomarkers (sAA and Cortisol) will be positively correlated with the attention changes detailed above.

6.3 Method

6.3.1 Participants

Forty-one healthy men and women aged 18 to 29 ($\bar{x}$ *age* = 20.80 yrs, *SD* = 2.49 yrs) participated in the experiment. They were assigned to either a control condition (Warm Pressor Task: n = 21, [15 female], $\bar{x}$ age = 21.01 yrs, SD = 2.74 yrs), or a stress condition (SECPT: n = 20, [14 female], $\bar{x}$ age = 20.05 yrs, SD = 2.24 yrs) using a randomised block design. Participants were recruited from staff and the student body at the University of

Southampton via an online research portal and on-campus advertisements. Each participant provided written informed consent and were compensated with a maximum of £18 or credits towards partial fulfilment of their course requirements upon termination of their session.

6.3.1.1 Exclusions

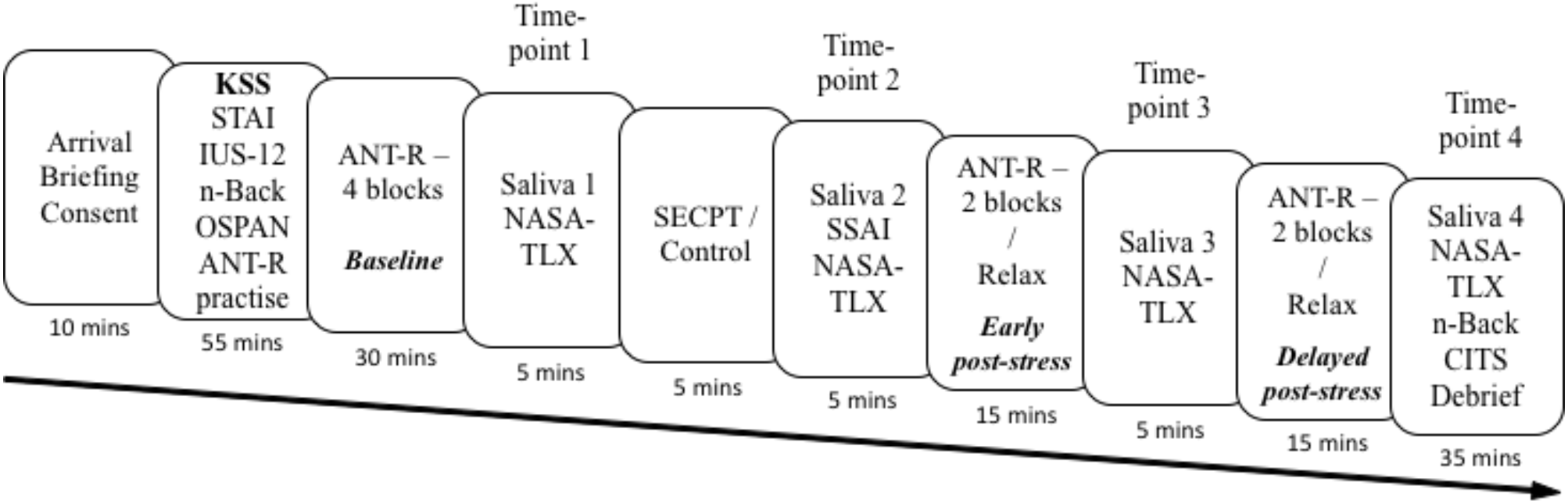
Exclusionary criteria were the same as Experiments One and Two, and are detailed in Chapter Three - Methodology. All participants achieved the minimum level of accuracy (Baseline) established in Chapter Three and were included in the initial data analyses (n = 41).

For analyses examining the physiological stress response (ANOVA) and how physiology influenced ANT-R performance (regressions), five participants were excluded as a result of their basal physiological data exceeding 2 SDs from the mean (n = 35).

6.3.2 Apparatus and Procedure

Apparatus and the procedure are as detailed in Chapter Three – Methodology and was almost identical to Experiment Two (Chapter Five). However, in the current experiment all participants attended in the morning, with sessions beginning at either 09:15 or 09:30. Additionally, participants were asked to complete an additional measure on arrival, the Karolinska Sleepiness Scale (KSS), in order to record their awakening time and sleepiness state. As the experiment was taking place in the morning this information was included in order to account for the possibility of participants experiencing a Cortisol Awakening Response (CAR), albeit attentional performance was assessed outside the typical CAR window. The order of tasks can be seen in Figure 6.1.

Figure 6.1 Runtime order for Experiment Three



Schematic detailing the order of tasks that participants experienced during Experiment Three. The task order was identical to Experiment Two except participants also completed the KSS (Karolinska Sleepiness Scale – highlighted in bold) following arrival.

6.4 Results

6.4.1 Analysis design

In line with the previous two experiments, Greenhouse-Geisser corrected degrees of freedom were used in analyses where the assumption of sphericity was violated. Effect sizes include partial η^2, Cohens *d* and Glass's *Delta (*Δ). As with Experiment Two, in order to simplify the analyses, participants ANT-R data was organised so that T3 represented the post-stress relaxation period and T4 represented the post-stress ANT-R. Analyses were conducted in the same order as Experiment Two (Chapter Five). The data and a full set of analyses is available in Appendix E.

6.4.2 Groups – Stress vs Controls

Independent samples t-tests revealed no significant differences between the stress and control groups in gender, birth control, age, handedness, trait anxiety, intolerance of uncertainty, sleepiness (or time awake) or working memory (OSPAN) (all *p*'s > .057). Similarly, there was an equal share of participants tested in the "early" and "delayed" periods ($p = .883$).

Despite expectations, and counter to what was observed in previous experiments, the difference between the length of time controls participants kept their hand immersed compared to stress participants did not reach significance (control $\bar{x} = 180$ *seconds*, stress $\bar{x} = 163.75$ *seconds*) ($t(19) = 1.83$, $p = .083$, *Glass's* $\Delta = 16.25$).

6.4.2.1 Self-report measures

An independent samples t-test demonstrated a significant difference between stress and controls in State Anxiety (SSAI) immediately following the SECPT/control manipulation ($t(30.30) = -3.79$, $p = .001$, $d = 1.19$). As predicted, participants who undertook the SECPT reported themselves as experiencing significantly higher anxiety

during the task compared to participants who completed the equivalent warm water control task.

A series of 2 (Condition: Stress vs Control) x 4 (Time-point: T1 to T4) x 2 (Stress time-course: Early vs Delayed) repeated measures ANOVAs were performed on each of the seven workload measures (modified NASA-TLX), with an interaction of Condition and Time-point of interest. Significant interaction effects of Condition x Time-point were observed for each measure (all F's > 9.03, all p's < .001, partial η^2's > .2), except Temporal Demand ($F(2.15,79.7) = 1.63$, $p = .202$, partial $\eta^2 = .04$) and Performance ($F(2.46,90.98) = 2.3$, $p = .095$, partial $\eta^2 = .06$ – see Table 6.1). Planned comparisons using independent samples t-tests showed that there were significant differences for each workload measure immediately following the stressor (T2) (all p's < .001, all *Glass's* Δ's > 1.34) except for Performance, where the effect just failed to reach significance ($t(39) = 1.74$, $p = .090$). This indicates that compared to the control task, participants in the stress group rated the SECPT as significantly more demanding in each workload measure. However, they did not feel they performed the task any more or less successfully than controls. Interestingly, there were significant differences in five other workload measures (Mental and Temporal Demand, Effort, Frustration and Stress) at T4 – representing the point at which participants completed their post-manipulation ANT-R (all t's > -2.11, all p's < .044, *Glass's* Δ's > 1.09). This suggests that exposure to the SECPT unexpectedly resulted in participants finding their second ANT-R more demanding than controls and indicates a legacy effect of stress. There were no other significant differences between workload measures at any other time (all p's > .056).

Table 6.1 *Mean (SD) ratings by participants on Spielberger State Anxiety Index (SSAI – scores 0-80) and NASA-Task Load Index (scores 0-100) immediately following stress exposure or control (T2).*

		SSAI	Mental	Physical	Temporal
Condition	*n*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	21	28.29 *(6.06)*	7.48 *(13.42)*	7.1 *(8.92)*	6.76 *(11.79)*
Stress	20	38.4 *(10.38)*	50.1 *(32.32)*	74.25 *(26.65)*	22.55 *(19.11)*

		Performance	Effort	Frustration	Stress
Condition	*n*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Control	21	88.67 *(18.22)*	6.76 *(12.39)*	6.38 *(10.16)*	5.91 *(10.3)*
Stress	20	76.25 *(26.87)*	73.1 *(28.76)*	44.55 *(32.22)*	56.1 *(31.53)*

A 2 (Condition) x 3 (Coping) x 2 (Stress time-course) repeated measures ANOVA examined coping strategies and demonstrated a significant interaction effect of Condition x Coping ($F(2,74) = 3.57$, $p = .033$, partial $\eta^2 = .09$). Post hoc independent samples t-tests showed that stress participants engaged in significantly higher levels of task-focused coping ($t(39) = -2.99$, $p = .005$, Cohens $d = .94$) and emotion-focused coping ($t(24.21) = -2.48$, $p = .021$, $d = .78$) than controls. There was no difference in avoidance-focused coping ($p = .984$). The results matched those observed in Experiment Two (Chapter Five). As predicted, participants in the stress group engaged in significantly greater levels of task-focused coping, as well as emotion-focused coping than their control counterparts.

6.4.2.2 Alpha Amylase

For sAA reactivity, there was no main effect of Time ($p = .101$) and no interaction of Time x Condition ($F(3,84) = .35$, $p = .789$, partial $\eta^2 = .01$). However, planned paired samples t-tests, examining each Condition individually showed that whilst control sAA was not significantly different at any time-point (all p's > .332), stress participants experienced a significant increase of sAA from T1 to T2 ($t(17) = -2.93$, $p = .009$, $d = .54$) (for means see Table 6.2). There was no significant difference between any other time-points (see Figure 6.2) . These results offer support for the hypothesis that stress

participants would experience a significant increase to sAA in the period immediately following exposure to the SECPT.

Figure 6.2. Salivary Alpha Amylase values at four time-points.

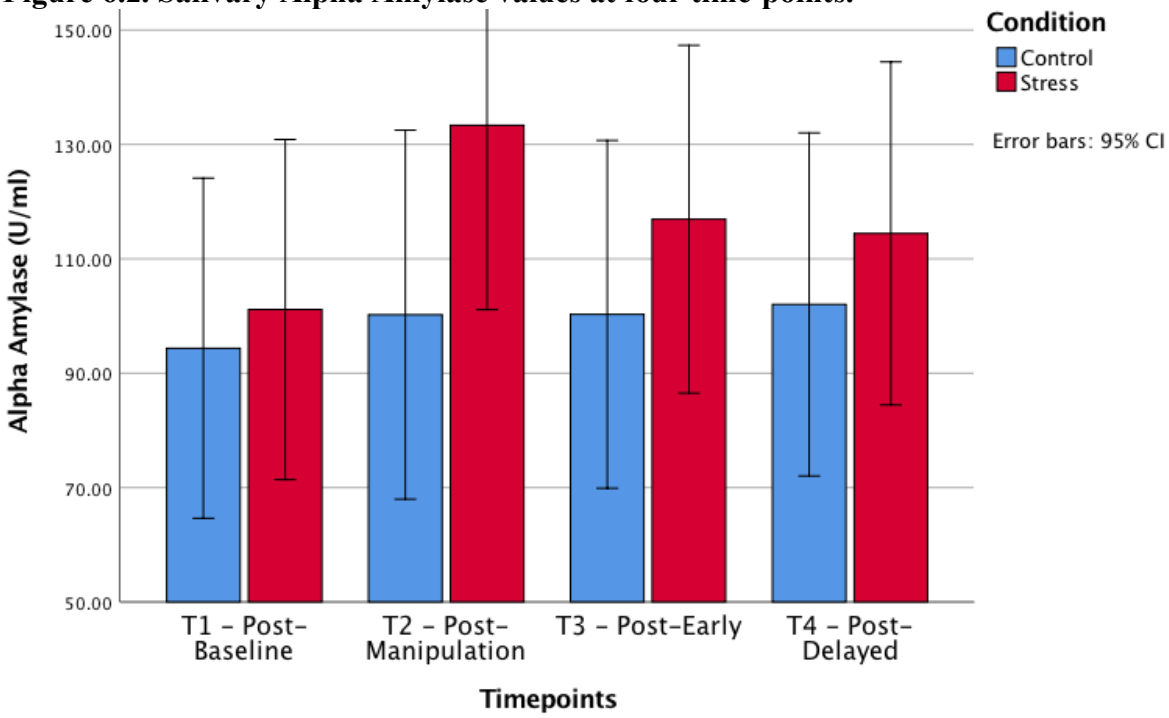


Figure 6.2. Graph demonstrates control participants observed no significant difference across the four time-points. However, participants in the stress group exhibited significantly elevated sAA at T2, compared to T1.

6.4.2.3 Cortisol

For Cortisol reactivity, there was a no significant main effect of Time ($F(1.22,33.9) = 2.63$, $p = .108$, partial $\eta^2 = .09$), but there was a significant interaction effect of Time x Condition ($F(1.22,33.9) = 6.94$, $p = .009$, partial $\eta^2 = .2$). Planned independent samples t-tests demonstrated significantly higher Cortisol values amongst stress participants at T3 than controls ($t(23.25) = -3.28$, $p = .003$, *Glass's* Δ's = 1.94). Furthermore, this significant difference continued at T4 ($t(27.91) = -2.77$, $p = .010$, $d = .93$), but at a reduced level compared to T3, thus indicating a recovery phase (Cortisol returning to baseline). Paired samples t-tests of each Condition showed that controls exhibited significant reductions in Cortisol from T1 to T3 ($t(17) = 5.91$, $p < .001$, $d = .4$) and T4 ($t(17) = 7.16$, $p < .001$, $d = .61$) (T2 - $p > .182$) . In contrast, stress participants demonstrated a significant increase

from T1 to T3 ($t(17) = -2.51$, $p = .023$, *Glass's* Δ's = 1.51) but not at any other point (all p's > .396) (see Figure 6.3). Both these results support the hypothesis that stress participants would exhibit a significant increase in Cortisol production at T3, following their experience of the SECPT (for means see Table 6.2). There were no significant differences at any other time (all p's > .539).

Figure 6.3 Salivary Cortisol values at four time-points.

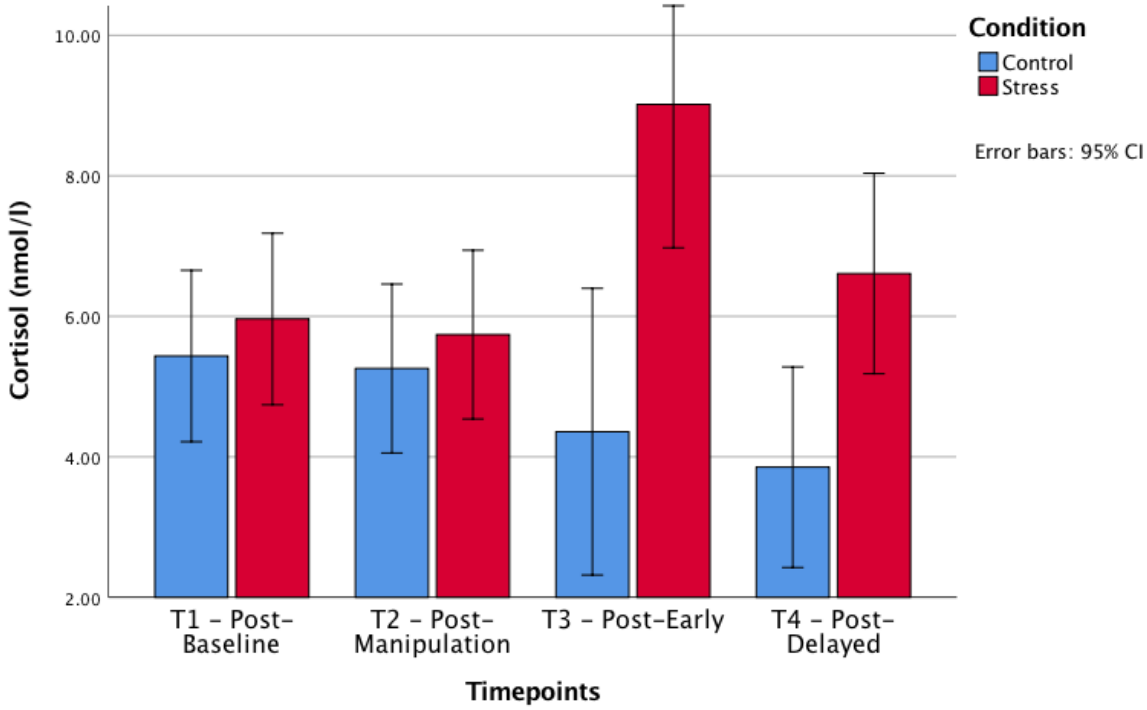


Figure 6.3. Graph demonstrates stress participants exhibited a significant peak in Cortisol production at T3. Conversely, controls participants Cortisol steadily reduced across the session.

Table 6.2 *Mean (SD) values of salivary Alpha Amylase (sAA – U/ml) and salivary Cortisol (nmol/l) by participants at four time-points.*

			Alpha Amylase (U/ml)*	Cortisol (nmol/l)^
	Condition	*n*	Mean *(SD)*	Mean *(SD)*
Time-point 1	Control	18	94.37 *(73.49)*	5.44 *(2.98)*
	Stress	18	101.13 *(48.05)*	5.96 *(2.03)*
Time-point 2	Control	18	100.24 *(72.69)*	5.26 *(2.76)*
	Stress	18	133.36 *(61.55)*	5.74 *(2.22)*
Time-point 3	Control	18	100.27 *(72.99)*	4.36 *(2.41)*
	Stress	18	116.92 *(52.24)*	9.02 *(5.52)*
Time-point 4	Control	18	102.02 *(70.82)*	3.85 *(2.18)*
	Stress	18	114.44 *(53.12)*	6.61 *(3.61)*

* sAA - Units per millilitre ^ Cortisol - nanomoles per litre

Additionally, to check for the possible influence of awakening on physiological reactivity, Pearson's correlations checked for any relationship between KSS score and "time awake" with sAA and Cortisol at each time point. However, these did not reach significance at any time (all p's > .152).

6.4.3 ANT-R

6.4.3.1 Measures

In line with Experiments Two and Three, four attentional measures were examined: alerting benefit, validity effect, orienting effect and flanker effect.

6.4.3.2 Reliability check

As in Experiments One and Two, the present experiment used a "split" run of the ANT-R. To validate the approach, split-half reliabilities were again calculated from baseline ANT-R data across all cue types for accuracy and RT. Pearson correlations showed that participants first half baseline performance significantly correlated with their performance during the second half of their baseline (all r's > .62, all p's < .001). Performance on flanker congruency was similarly correlated for RT (all r's > .82, all p's < .001). However, for accuracy, whilst incongruent flanker performance was significantly correlated (r = .93 p < .001), congruent flanker performance was not (r = .23, p = .147).

Importantly, this suggests that flanker accuracy (in the AM) is affected by repeated iterations and therefore may represent a less reliable measure. Despite this, Pearson's correlations showed that global measures of efficiency (accuracy / RT: Townsend and Ashby, 1983) were correlated across the pre- and post-tranches (r's > .904, all p's < .001). (see Table 6.3).

6.4.3.3 Effects Check

Paired samples t-tests examined whether the ANT-R was producing the expected attentional effects. With the exception of alerting benefit accuracy ($t(40) = -.98$, $p = .335$, $d = .09$), all effects (both accuracy and RT) were significant (all p's < .051, all d's > .13), and in the expected direction. Although the alerting benefit (accuracy) was not significant, the means indicate that performance was in the expected direction (No Cue $\bar{x}$ accuracy = 91.41%, Double Cue $\bar{x}$ accuracy = 92.23%).

Table 6.3 *Correlation matrix from Pre- and Post-manipulation performance (Accuracy and RT).*

		Global Accuracy	Global RT
		Post-manipulation	Post-manipulation
Global Accuracy	Pearsons *r*	.933*	
Pre-manipulation	Sig. (2-tailed)	.000	
Global RT	Pearsons *r*		.904*
Pre-manipulation	Sig. (2-tailed)		.000

* Correlation is significant at the 0.001 level

6.4.3.4 ANT-R Performance Data

6.4.3.4.1 Global Effects

Global accuracy was calculated for each participant and analysed using a 2 (Condition: Stress vs Control) x 2 (ANT-R Tranche: Pre-stress vs Post-stress) x 2 (Stress time-course: Early vs Delayed) x 2 (Gender: Male vs Female) repeated measures ANOVA.

There was no significant main effect of Tranche (p = .174). However, there was a significant interaction effect of Tranche x Condition (F(1,33) = 8.25, p = .007, partial η^2 = .2). An independent samples t-test showed no significant difference between stress and controls at neither pre- nor post-manipulation. However, when examining each condition independently, paired samples t-tests showed that whilst control participants did not differ between pre- and post- (p =.318) (Pre- $\bar{x}$ accuracy = 91.04%, Post- $\bar{x}$ accuracy = 91.77%), stress participants did (t(19) = 2.48, p = .023, d = .17). The means indicate that stress participants accuracy slightly, but significantly deteriorated following exposure to the SECPT (Pre- $\bar{x}$ accuracy = 92.76%, Post- $\bar{x}$ accuracy = 91.04%). There were no other significant effects (all p's > .140). See Table 6.4 for means and standard deviations.

An identical 2 x 2 x 2 x 2 repeated measures ANOVA conducted for RT showed there was a significant main effect of Tranche (F(1,33) = 11.02, p = .002, partial η^2 = .25). A paired samples t-test indicated RT was significantly quicker in the post-stress ANT-R compared to the Pre-stress ANT-R (t(40) = 4.01, p < .001, d = .28). There were no other significant effects (all p's > .099). See Table 6.4 for means and standard deviations.

Table 6.4 *Mean (SD) values of global accuracy and RT performance across the three tranches of the ANT-R.*

			Pre-stress		Early		Delayed
	Condition	*n*	Means *(SD)*	*n*	Means *(SD)*		Means *(SD)*
Accuracy *(%)*	Control	21	91.04 (7.73)	11	90.4 (9.95)	10	93.26 (4.47)
	Stress	20	92.76 (9.75)	10	88.82 (14.35)	10	93.26 (4.45)
	Total	41	91.88 (8.72)	21	89.65 (11.95)	20	93.26 (4.36)
RT *(ms)*	Control	21	583.35 (80.2)	11	547.15 (70.3)	10	585.18 (73.23)
	Stress	20	579.05 (71.97)	10	521.8 (56.83)	10	591.31 (56.77)
	Total	41	581.25 (75.37)	21	535.08 (63.97)	20	588.24 (63.85)

6.4.3.4.2 Alerting Benefit

A 2 (Condition: Stress vs Control) x 2 Tranche (Pre- vs Post-) x 2 (Stress time-course: Early vs Delayed) x 2 (Gender: Male vs Female) repeated measures ANOVA was performed. With regard to accuracy, there were no significant main or interaction effects

(all p's > .697) indicating that neither exposure to stress, nor gender had any impact on alerting benefit accuracy.

Regarding RT, there was an interaction of Tranche x Condition ($F(1,33) = 4.55$, p = .040, partial η^2 = .12). Planned paired samples t-tests examined each condition individually and revealed that control participants performance did not differ from pre- to post- manipulation (p = .534). However, stressed participants demonstrated a significantly smaller alerting benefit compared to their baseline ($t(19) = 3.18$, p = .005, *Glass's* Δ's = 1.5). No other effects reached significance (p = .390).

6.4.3.4.3 Validity Effect

Regarding accuracy, again there were no significant main or interaction effects of interest (all p's > .179) indicating that validity effect accuracy was not impacted by exposure to morning stress, its time-course or gender.

With respect to RT, there was a significant interaction effect of Tranche x Condition ($F(1,33) = 6.73$, p = .014, partial η^2 = .17). Planned post-hoc paired samples t-tests were performed for each condition individually. Neither control nor stress participants displayed a significant difference in validity effect between pre- and post-manipulation/stress measurement (both p's > .114). An independent samples t-test examining pre- and post- validity effects by condition instead revealed baseline differences. This indicated that participants in the stress group had initially demonstrated a larger validity effect than controls ($t(39) = -2.27$, p = .029, *Glass's* Δ's = .61) and would account for the significant interaction observed. No other main or interaction effects of interest reached significance (all p's > .101).

6.4.3.4.4 Orienting Effect

An ANOVA examined the orienting effect and demonstrated no significant main or interaction effects of interest for accuracy (all p's > .290) or for RT (all p's > .237). The

results suggest that exposure to stress, its time-course, and gender have no impact upon the orienting effect.

6.4.3.4.5 Flanker Effect

An ANOVA examining the flanker effect found a significant interaction effect of Tranche x Condition ($F(1,33) = 12.73$, $p = .001$, partial $\eta^2 = .28$). Post hoc paired samples t-tests indicate that whilst control performance did not differ from baseline ($p = .248$), stressed participants exhibited a difference that approached significance ($t(19) = 2.07$, $p = .053$, $d = .12$). The means indicate stress led to a larger flanker effect post-stress. There was also a significant three-way interaction of Tranche x Condition x Gender ($F(1,33) = 9.61$, $p = .004$, partial $\eta^2 = .23$). Post hoc ANOVAs demonstrated a significant interaction of Tranche x Condition for males ($F(1,10) = 20.38$, $p = .001$, partial $\eta^2 = .67$), but not females ($p = .721$). Paired samples t-tests examining male controls indicate a reduced flanker effect post-manipulation ($t(5) = -4.85$, $p = .005$, $d = .23$). Alternatively, male stress participants demonstrated a larger flanker effect post-stress ($t(5) = 3.03$, $p = .029$, $d = 1$). The results suggest that exposure to stress leads to an enlarged flanker effect compared to controls. Further, it appears the effect is greatest amongst males, where the absence of a stressor also leads to a smaller flanker effect. There were no other significant effects (all p's > .340).

For RT, the ANOVA revealed no significant main or interaction effects of interest (all p's > .253) indicating that stress, it's time course and gender have no impact on flanker effect RT.

The results show that for RT, only alerting network efficiency evolved differently for stress and control participants over the course of the experiment. The original hypothesis predicted that stressed participants would demonstrate an increased alerting benefit, relative to their control counterparts, during the early and delayed periods. Instead, the results show that whilst control participants exhibited a non-significant

increase to their alerting benefit, stress participants alerting benefit significantly reduced. This would suggest that exposure to stress in the morning reduces alerting. The analyses also indicated a difference of condition on the validity effect, but further investigation revealed this was the result of baseline differences, rather than any influence of stress exposure.

Regarding accuracy, the hypothesis was that the flanker effect would reduce amongst stress participants. Instead, the flanker effect increased following stress. Further, although the increase was greater in stressed males, this was also coupled with male controls exhibiting a significantly reduced flanker effect.

6.4.4 Physiological Influence – ANT-R Regressions.

A series of regressions investigated how physiological activity following stress might influence ANT-R performance.

6.4.4.1 Data sanitisation

As a result of incomplete or unsuitable physiological data (for details, see section 6.3.1.1) five participants were excluded from this portion of analysis.

6.4.4.2 Predictors

In line with the previous experiment, common predictors included Gender, OSPAN and Task-focused coping (CITS). Additionally, "time awake" was included to understand any underlying influence of a possible CAR effect. Baseline tranche regressions also included Condition, Trait Anxiety (STAI) as well as basal physiology (T1 sAA and Cortisol). For early and delayed tranche regressions, State Anxiety (SSAI) was included as a proxy for condition, whilst aggregated Intolerance of Uncertainty (IUS-12) was included instead of STAI to prevent issues of multicollinearity with physiology measures. T2 sAA / Cortisol was included for early regressions, whilst T3 sAA / Cortisol was included for delayed regressions. In line with previous experiments, the biomarker measurements used were absolute values (not differences scores). As with Experiments One and Two,

multiple regressions using the difference scores were not materially different from the absolute values, therefore only absolute values are reported.

6.4.4.3 Results

Baseline: Basal physiology did indicate some predictive value towards attentional performance (RT), with higher sAA significantly predicting smaller validity effects (p = .019, β = -.39) and orienting effects (p = .012, β = -.43). Higher basal Cortisol also shared a relationship with larger orienting effects (RT) (p = .042, β = .33). The flanker effect (RT) also shared a significant negative relationship with trait anxiety (p = .039, β = -.38). No other predictors were significant (all p's > .078 – see Tables 6.5 and 6.6).

Early: Higher T2 sAA was related to smaller alerting benefits (accuracy) (p = .051, β = .57), whilst higher Cortisol at T2 was estimated to share a significant relationship with larger validity effects (RT) (p = .015, β = .81). Additionally, both higher state anxiety (p = .035, β = -.73) and increased "time awake" (p = .053, β = -.7) were estimated to predict increased alerting benefits (accuracy). No other predictors were significant (all p's > .086 – see Tables 6.5 and 6.6).

Delayed: Neither of the physiological measures shared a relationship with any attentional measure. Only working memory (OSPAN) was estimated to share a significant relationship with the orienting effect (accuracy – p = .041, β = .52). No other relationships reached significance (all other p's > .065 – See Tables 6.5 and 6.6).

The results demonstrate some evidence for stress-linked physiology influencing attentional performance. Higher basal level of sAA was shown to share a relationship with reduced orienting and validity effects, whilst higher Cortisol was related to a larger orienting effect. However, both of these were prior to the administration of the SECPT and therefore represent individual differences in homeostatic physiology rather than the influence of stress exposure. Interestingly, higher sAA production immediately following the manipulation was related to a smaller alerting benefit. This matched the behavioural

data that showed stressed participants also exhibited a reduction to the alerting benefit post-SECPT. Higher Cortisol during this period was also linked to an increased validity effect, however this was not supported by the behavioural data. Regarding anxiety, whilst higher trait levels was associated with a reduced flanker effect at baseline, higher state anxiety reflected an increased alerting benefit in the immediate aftermath of stress, as did being awake longer (minutes awake). Finally, higher working memory (OSPAN) was related to a reduced orienting effect in the delayed period.

Table 6.5 *Regression table showing predictors at each tranche (baseline / early / delayed) for each of the four attentional effects (Accuracy).*

Accuracy	Baseline			Early			Delayed		
	Beta	*p*	Predictor	Beta	*p*	Predictor	Beta	*p*	Predictor
Alerting Benefit	-0.28	0.187	Condition	0.55	0.192	Gender	0.35	0.244	Gender
	-0.07	0.701	Gender	-0.55	0.086	OSPAN	-0.09	0.684	OSPAN
	-0.19	0.313	OSPAN	-0.35	0.207	IUS Agg	-0.50	0.065	IUS Agg
	-0.10	0.594	STAI	-0.73	0.035 *	SSAI	-0.07	0.803	SSAI
	0.09	0.663	Task Coping	-0.13	0.665	Task Coping	-0.46	0.157	Task Coping
	-0.36	0.078	Mins awake	-0.70	0.053 ^	Mins awake	-0.28	0.325	Mins awake
	0.17	0.376	T1 sAA	0.57	0.051 ^	T2 sAA	0.36	0.228	T3 sAA
	0.19	0.306	T1 Cortisol	0.15	0.598	T2 Cortisol	-0.09	0.729	T3 Cortisol
Validity Effect	-0.03	0.902	Condition	0.52	0.335	Gender	0.50	0.203	Gender
	0.30	0.142	Gender	-0.34	0.394	OSPAN	0.09	0.762	OSPAN
	-0.15	0.436	OSPAN	0.16	0.645	IUS Agg	0.14	0.656	IUS Agg
	-0.07	0.726	STAI	0.11	0.790	SSAI	0.15	0.668	SSAI
	-0.06	0.748	Task Coping	-0.01	0.990	Task Coping	0.42	0.302	Task Coping
	0.05	0.794	Mins awake	-0.36	0.410	Mins awake	-0.18	0.622	Mins awake
	0.23	0.229	T1 sAA	0.18	0.610	T2 sAA	-0.32	0.400	T3 sAA
	0.18	0.325	T1 Cortisol	-0.02	0.960	T2 Cortisol	-0.16	0.632	T3 Cortisol
Orienting Effect	0.00	0.992	Condition	-0.12	0.801	Gender	0.36	0.213	Gender
	0.30	0.134	Gender	0.34	0.334	OSPAN	0.52	0.041 *	OSPAN
	0.11	0.575	OSPAN	0.48	0.146	IUS Agg	0.46	0.072	IUS Agg
	0.08	0.652	STAI	0.59	0.128	SSAI	0.00	0.997	SSAI
	-0.24	0.231	Task Coping	-0.31	0.366	Task Coping	0.54	0.093	Task Coping
	0.12	0.534	Mins awake	0.38	0.336	Mins awake	-0.12	0.644	Mins awake
	-0.05	0.806	T1 sAA	-0.39	0.219	T2 sAA	-0.42	0.151	T3 sAA
	-0.06	0.748	T1 Cortisol	0.05	0.877	T2 Cortisol	-0.13	0.620	T3 Cortisol
Flanker Effect	0.00	0.989	Condition	0.51	0.297	Gender	0.55	0.197	Gender
	0.15	0.462	Gender	0.20	0.578	OSPAN	-0.01	0.984	OSPAN
	0.26	0.182	OSPAN	-0.28	0.394	IUS Agg	0.06	0.848	IUS Agg
	-0.06	0.762	STAI	-0.42	0.275	SSAI	0.06	0.880	SSAI
	0.12	0.542	Task Coping	0.17	0.618	Task Coping	0.25	0.558	Task Coping
	-0.16	0.426	Mins awake	-0.61	0.138	Mins awake	-0.20	0.612	Mins awake
	-0.13	0.496	T1 sAA	0.44	0.184	T2 sAA	-0.08	0.843	T3 sAA
	0.16	0.397	T1 Cortisol	0.15	0.656	T2 Cortisol	-0.09	0.797	T3 Cortisol

* denotes significant to < .05 level ^ denotes trend

Table 6.6 *Regression table showing predictors at each tranche (baseline / early / delayed) for each of the four attentional effects (Reaction Time).*

RT	Baseline			Early			Delayed		
	Beta	*p*	Predictor	Beta	*p*	Predictor	Beta	*p*	Predictor
Alerting Benefit	0.27	0.187	Condition	0.25	0.601	Gender	0.00	0.993	Gender
	0.19	0.313	Gender	-0.26	0.465	OSPAN	0.31	0.251	OSPAN
	-0.12	0.504	OSPAN	0.53	0.119	IUS Agg	0.30	0.279	IUS Agg
	0.25	0.157	STAI	-0.02	0.959	SSAI	-0.07	0.815	SSAI
	-0.06	0.738	Task Coping	-0.63	0.088	Task Coping	-0.21	0.541	Task Coping
	0.15	0.425	Mins awake	-0.17	0.669	Mins awake	0.02	0.951	Mins awake
	0.14	0.428	T1 sAA	0.06	0.842	T2 sAA	-0.46	0.173	T3 sAA
	-0.23	0.178	T1 Cortisol	0.46	0.185	T2 Cortisol	-0.19	0.522	T3 Cortisol
Validity Effect	0.28	0.131	Condition	0.04	0.930	Gender	-0.06	0.887	Gender
	-0.03	0.853	Gender	-0.13	0.674	OSPAN	-0.19	0.588	OSPAN
	0.11	0.492	OSPAN	-0.05	0.864	IUS Agg	0.11	0.767	IUS Agg
	-0.09	0.590	STAI	0.17	0.589	SSAI	-0.17	0.655	SSAI
	0.25	0.138	Task Coping	-0.40	0.189	Task Coping	0.14	0.754	Task Coping
	0.27	0.117	Mins awake	0.01	0.967	Mins awake	0.14	0.739	Mins awake
	-0.39	0.019 *	T1 sAA	-0.09	0.744	T2 sAA	0.00	0.998	T3 sAA
	0.18	0.241	T1 Cortisol	0.81	0.015 *	T2 Cortisol	0.35	0.380	T3 Cortisol
Orienting Effect	-0.07	0.702	Condition	0.10	0.857	Gender	-0.12	0.748	Gender
	0.03	0.854	Gender	0.14	0.722	OSPAN	-0.44	0.154	OSPAN
	0.13	0.427	OSPAN	-0.51	0.168	IUS Agg	0.13	0.669	IUS Agg
	-0.21	0.191	STAI	-0.05	0.911	SSAI	-0.15	0.643	SSAI
	0.13	0.459	Task Coping	0.11	0.770	Task Coping	0.34	0.380	Task Coping
	0.23	0.186	Mins awake	0.05	0.909	Mins awake	-0.16	0.652	Mins awake
	-0.43	0.012 *	T1 sAA	0.08	0.828	T2 sAA	-0.20	0.580	T3 sAA
	0.33	0.042 *	T1 Cortisol	0.30	0.413	T2 Cortisol	0.04	0.902	T3 Cortisol
Flanker Effect	-0.19	0.337	Condition	0.21	0.678	Gender	0.30	0.320	Gender
	0.32	0.091	Gender	-0.24	0.514	OSPAN	-0.22	0.364	OSPAN
	-0.11	0.562	OSPAN	-0.15	0.665	IUS Agg	-0.47	0.082	IUS Agg
	-0.38	0.039 *	STAI	0.02	0.968	SSAI	0.14	0.598	SSAI
	0.07	0.715	Task Coping	0.47	0.208	Task Coping	-0.38	0.242	Task Coping
	0.14	0.464	Mins awake	0.18	0.662	Mins awake	0.36	0.223	Mins awake
	0.05	0.772	T1 sAA	-0.10	0.755	T2 sAA	0.17	0.561	T3 sAA
	0.07	0.680	T1 Cortisol	-0.48	0.185	T2 Cortisol	0.35	0.209	T3 Cortisol

* denotes significant to < .05 level

6.5 Discussion

The purpose of the present study was to examine how exposure to acute stress in the morning impacts attentional performance as measured by the ANT-R. Previous experiments have examined the effects of stress in the afternoon in order to minimise any potential confounding effects of the Cortisol Awakening Response (CAR) as well as collect Cortisol when levels are low, and relatively stable. Following awakening, the CAR is characterised by basal levels of Cortisol reaching their daily peak approximately one hour later, before slowly diminishing over the course of the day. However, Cortisol levels can remain volatile in the period following this awakening response (Nater et al., 2007; Smyth et al., 1997). Cortisol's usefulness as a reliable indicator of stress state has therefore guided researchers to measure stress predominantly in the afternoon, outside of the CAR period and when levels are usually lower and more stable. However, Vargas and Lopez-Duran (2017) reported that the CAR is reliant on awakening and not simply a circadian process. Therefore, shift workers, late-risers or those on reduced sleep patterns will likely experience CAR of different magnitudes, at different times of the day (Bostock & Steptoe, 2013; Fries et al., 2009; Wirth et al., 2011). Furthermore, as stress is experienced across the day, and not just in the afternoon when basal levels are low, it is important to understand whether stressed performance is different in the morning compared to the afternoon. Thus, the experiment aimed to understand how exposure to stress in the morning might impact performance. Additionally, even though performance was tested outside of the typical CAR window, measures were collected to explore whether the proximity of testing to the CAR influenced performance.

6.5.1 Stress Induction

The efficacy of the stress induction was assessed using both self-report and physiological measures. In accordance with Hypothesis One, participants who were exposed to acute psychosocial stress (SECPT) reported their experience as significantly

more demanding and stressful than participants in the control group. Further, participants required greater effort, rated their own performance as poorer and expressed higher levels of state anxiety following the stressor. They also engaged in significantly greater levels of both task-focused and emotion-focused coping.

Additionally, participants physiological responses to the control and stressor tasks matched Hypothesis Two. Specifically, sAA level significantly increased immediately following the SECPT task (T2), but not following the control task. Participants who experienced the SECPT also exhibited significantly increased Cortisol at T3 (~15 minutes post-stressor). However, Cortisol levels in control participants steadily reduced over the duration of the experiment.

6.5.2 ANT-R Performance

The ANT-R was used to measure efficiency of attentional performance at three time-points. Participants completed a baseline ANT-R (four blocks), then a single post-manipulation ANT-R (two blocks) either immediately following the manipulation (0-15 minutes), or in a delayed period (~20-35 minutes). Pearson's correlations showed that irrespective of these separate periods, global accuracy and global RT was higher correlated from pre- to post-manipulation. In line with the previous studies, use of split-half ANT-R's was assessed using baseline performance and showed good support for the approach. Notably however, when assessing flanker congruency, correlations did not reach significance for congruent flanker trials. The data suggests that across the baseline ANT-R measure, performance on congruent flanker trials differed between the first two blocks and the latter two blocks. This is an important consideration for the later results as it suggests that the change to the flanker effect might not be reliably measured via a split-half design in the current sample, despite previous evidence to the contrary (Experiments One and Two).

6.5.2.1 Stress and the ANT-R

The results indicate that with regard to RT, there was no change to attentional performance on the orienting network (orienting effect) or the executive control network (flanker effect). Initial analyses indicated that the validity effect was different between participants in the stress and control group, however this was observed as a result of baseline differences.

The magnitude of the alerting effect however, was altered between groups following stress exposure. Hypervigilance following stress has been well documented (Henckens et al., 2012; Thayer & Brosschot, 2005), as has the neural basis for such change (Hermans et al., 2011; van Marle et al., 2009; Weymar et al., 2012). However this is usually at the cost of specificity, or higher distractibility (Skosnik et al., 2000; van Marle et al., 2009). In the present study, participants who had undertaken the SECPT demonstrated a smaller alerting benefit, relative to those in the control group. The result was contrary to that hypothesised (H3) and appears to contradict data observed in Experiment Two, when the alerting benefit increased in magnitude due to a hypervigilance effect. Despite this incongruous change to the magnitude of the alerting benefit, further examination of the effect shows that it is still driven by an increase to vigilant state, albeit manifesting differently to what was observed in Experiment Two. The data show that participants who experienced the SECPT exhibited a significantly smaller benefit to their alerting (30.74 *ms*) compared to their baseline (53.84 *ms*). Conversely, alerting benefits for control participants increased by a non-significant amount (45.73 *ms* to 53.4 *ms*). However, a closer examination of the trial means used to calculate the alerting benefit reveal that participants from both groups exhibited improved performance on both types of trial (No Cue and Double Cue). Importantly though, the improvements exhibited by stress participants on "no cue" trials were substantially larger than the improvement demonstrated by control participants (see Table 6.7 for cue means). Speeded RT on trials with no cue would suggest that participants were able to react more quickly to the

appearance of a target, and that this effect was significantly enhanced in those exposed to stress. Interestingly, this reduction in alerting benefit was independent of the post-manipulation measurement periods (early / delayed), implying that the effect was induced by stress, but was not dependent on its time course as was previously demonstrated in Experiment Two. Whilst the results do not directly support the hypothesis made in the Introduction, it appears the mechanism driving the change was the same as reported in Experiment Two.

Table 6.7 *Mean (SD) RT of trials (cues) used to calculate Alerting Benefit for both stress and controls, across baseline and post-manipulation ANT-R's.*

	Condition	*n*		Means *(SD)*	Alerting Benefit	Cue improvement
Baseline	Control	21	No Cue	633.14 (80.18)		
			Double Cue	587.41 (84.79)	45.73 *ms*	
	Stress	20	No Cue	632.60 (76.45)		
			Double Cue	578.76 (67.80)	53.84 *ms*	
Post-manipulation	Control	21	No Cue	616.78 (81.63)		16.36 *ms*
			Double Cue	563.38 (71.41)	53.4 *ms*	24.03 *ms*
	Stress	20	No Cue	598.59 (68.69)		**34.01 *ms***
			Double Cue	567.85 (72.45)	30.74 *ms*	10.91 *ms*

***Bold indicates the trial type thought to be driving any change**

Although exposure to acute stress did not lead to a change to the flanker effect with regard to RT, accuracy did appear to be altered. Following exposure to stress, participants exhibited a significantly larger flanker effect (14.86 %) than they did at baseline (12.53 %). Conversely, participants who underwent to warm water task saw a non-significant reduction from baseline (14.48 %) to their post-manipulation ANT-R (13.03 %). Although observed on accuracy, the results again appear contradictory to those observed in Experiment Two when the flanker effect reduced following stress exposure. However, as was the case in Experiment Two, the effect here appears driven by impaired decision making or the suppression of a practice effect that was otherwise exhibited by controls. To illustrate, between their baseline and post-manipulation run, control participants improved

on incongruent cues (by 1.45 %) and matched performance on congruent cues (close to ceiling at 98.28 %). However, exposure to the SECPT resulted in stress participants performance worsening on both incongruent and congruent cues by 2.88 % and .56 %, respectively (see Table 6.8). Whilst the performance deterioration on congruent cues is not significant and may result from baseline performance being close to ceiling, the deterioration on incongruent cues is greater and explainable as a reduced practice effect or impaired decision making. Therefore, the data offers further support for the results of Experiment Two which indicated reduced practice effects or impaired learning, as opposed to a global broadening (Skosnik et al., 2000) or narrowing of attention (Chajut & Algom, 2003). Although suppression of practice and impaired learning has previously been demonstrated in both memory and spatial working memory studies (Holscher, 1999; Schwabe & Wolf, 2010), the present studies appear to be the first to demonstrate the effect in an attentional task.

Table 6.8 *Mean (SD) RT of trials (congruency) used to calculate Flanker Effect for both stress and controls, across baseline and post-manipulation ANT-R's.*

	Condition	*n*		Means *(SD)*	Flanker Effect	Flanker Improvement
Baseline	Control	21	Incongruent	83.80 (14.45)		
			Congruent	98.28 (1.83)	-14.48 %	
	Stress	20	Incongruent	86.49 (18.78)		
			Congruent	99.03 (1.07)	-12.53 %	
Post-	Control	21	Incongruent	85.25 (13.6)		1.45 %
			Congruent	98.28 (2.70)	-13.03 %	0 %
	Stress	20	Incongruent	83.61 (20.39)		**-2.88 %**
			Congruent	98.47 (1.8)	-14.86 %	**-0.56 %**

Furthermore, the above change to flanker effect appears to be more evident when examining male participants. This is because the flanker effect is both significantly reduced for male control participants (from 20.37 % to 16.2 %) and significantly increased for stress participants (11.69 % to 18.75 %). Once again, the change appears to be driven by stressed participants performance on incongruent trials being significantly poorer (-7.41

%). The data would suggest that the suppression of practice was more profound in males when tested in the morning (see Table 6.9). Importantly, it should be noted that the power of the final finding is greatly reduced, relative to other results reported (also Experiments One and Two) due to the small sample size of males (n = 12). Therefore, any conclusion should be made with caution.[7]

Table 6.9 *Mean (SD) RT of trials (congruency) used to calculate Flanker Effect for Male stress and control participants, across baseline and post-manipulation ANT-R's.*

Males	Condition	*n*		Means *(SD)*	Validity Effect	Cue Improvement
Pre-	Control	6	Incongruent	78.01 (21.5)		
			Congruent	98.38 (2.73)	-20.37 %	
	Stress	6	Incongruent	87.27 (5.26)		
			Congruent	98.96 (0.85)	-11.69 %	
Post-	Control	6	Incongruent	81.02 (20.93)		3.01 %
			Congruent	97.22 (4.3)	-16.2 %	1.16 %
	Stress	6	Incongruent	79.86 (9.45)		**-7.41 %**
			Congruent	98.61 (2.15)	-18.75 %	0.35 %

An additional aim of the study was to examine whether stress-induced physiology directly influenced attentional performance (H7). This was of particular interest in the present study given the common practice of measuring stress-induced changes in the afternoon in order to minimise any potential confounding effect of the CAR (Alomari et al., 2015; Skoluda et al., 2015). A series of regressions offered some modest support for a relationship between strength of physiological response and altered attentional performance. Higher sAA levels immediately following the manipulation (note: significantly higher in those experiencing the SECPT) shared a significant relationship with reduced alerting benefits. This observation matched the behavioural evidence whereby participants who had experienced the SECPT also demonstrated a significantly

[7] Despite the small sample size, the male-only ANOVA demonstrated a strong effect (partial η^2 = .67), whilst the t-test comparing stress and controls participants was also strong (Cohens d = 1).

reduced alerting benefit. At the same point (T2) increased Cortisol was also associated with a larger validity effect, however, this was before the peak in Cortisol level would be expected to occur (T3). Further, the behavioural data failed to show any effect of stress on validity. Instead, a relationship between higher Cortisol and enlarged validity effects was present at baseline. This suggests the relationship was less a result of stress-induced physiology and more as a result of individual differences. In contrast, higher basal sAA was related to smaller validity effects (and orienting effects) offering further support for the difference resulting from individual differences, as opposed to stress-induced physiology.

Experiment Two demonstrated little evidence of stress-induced physiology directly influencing attentional performance. However, by measuring the effect of stress on attention in the morning, Experiment Three demonstrated that the physiological change associated with experiencing acute stress appears to share a direct relationship with limited aspects of cognitive performance. Existing literature has described such a relationship previously, however reports often focused on Cortisol, and was often as a result of separating participants into "responders" and "non-responders" (Al'Absi et al., 2002; Bohnen et al., 1990; Domes et al., 2004). Rather than separating participants based on a median split, as is often the case in the literature, the present experiment simply considered the level of physiological activity following stress (or lack thereof).

The results offered no evidence that Cortisol influenced attentional performance following stress, nor was basal Cortisol significantly related to the amount of time awake (minutes awake), nor sleepiness (KSS), indicating that the period of measurement was not confounded by the CAR. Thus, the results suggest that the common practice of conducting stress experiments during the afternoon might miss the opportunity to better understand how stress influences cognition at other times of the day (e.g. during the morning when levels are typically higher and more volatile). Provided future studies measure performance outside of the traditional CAR window (0-60 minutes; Kudielka et al., 2012),

there seems to be no apparent risk of the results being influenced or confounded by the CAR.

The results did highlight the importance of the SNS in the explanation of cognitive change following stress, as higher sAA levels following stress exposure (indicative both of greater stress and increased SNS activity) was linked to attentional performance differences. The evidence that greater SNS activity following stress might influence attention is important, as SNS activity also varies over the course of the day, and may, in fact, impart a greater influence on cognition than previously hypothesised. Few studies have explored the direct influence of physiology of cognitive change (Bohnen et al., 1990; Pilgrim, Marin, & Lupien, 2010), preferring to simply use increased Cortisol/sAA production as evidence of stressed state (Robinson et al., 2013). However even those that have, might have underestimated the potential influence of the SNS if they limited themselves to collecting data in the afternoon, as SNS activity fluctuates naturally throughout the day.

6.5.2.2 Other factors and the ANT-R

At baseline, higher trait anxiety was associated with a reduced flanker effect, while increased state anxiety was associated with a larger alerting benefit immediately following the manipulation. Interestingly, despite both state and trait anxiety sharing a strong relationship to stress state, these appeared to contradict the behavioural data where stress was related to larger flanker effects and smaller alerting benefits. This is most surprising for state anxiety which was strongly correlated to stressed state following the SECPT and would appear to highlight the importance of physiology, as opposed to appraisal in the present study. In addition, the number of minutes since awakening – included as a proxy for the CAR – was related to reduced alerting benefits. However, if the CAR had influenced attention, shorter periods since awakening would be expected to predict performance (since the first saliva collection took place a minimum of two hours after

awakening). Finally, in contrast to previous results, it was observed that working memory (OSPAN) shared little in common with attentional performance. However, for the specific trials used to calculate the orienting effect, higher working memory led to more consistent performance during the delayed period.

6.5.3 Limitations

The purpose of the present study was to capture the influence of stress on attentional performance in the morning. Up to this point, stress researchers appear to have focused their investigations on afternoon effects, fearing that measuring performance in the morning might be confounded by the Cortisol Awakening Response, whilst levels are typically lower/more stable levels in the afternoon. The data show that morning studies are feasible provided measurements are taken outside of the known CAR period (0-60 minutes). Further they might also be able to identify elements that might otherwise be missed when conducting studies exclusively in the afternoon, such as the impact of SNS activity, which appears to be influential in the morning, but not in the afternoon (see Chapter 5 – Experiment 2). In the present study, all participants indicated they had been awake for 40 minutes or more prior to attending, whilst their first ANT-R commenced at least 65 minutes into the session, meaning at least 105 minutes had passed between awakening and completing their first attention task. Therefore, as the Cortisol Awakening Response window is during the first 60 minutes following awakening (Fries et al., 2009; Kudielka et al., 2012), it was unlikely that the CAR would exert an influence on either attentional performance or the stress response so long after awakening. However, the results now provide empirical evidence that stress studies can be performed successfully in the morning and that they might provide a more complete understanding of stress cognition. Nevertheless, although the results provide evidence supporting the utilisation of morning experiments, future work should also aim to examine performance much closer to awakening in order to accurately understand the influence, if any, of the CAR.

In the present study, observed sAA reactivity fully supported the hypothesis that sAA level would be increased for participants in the stress group, but not controls (H2). Across the earlier experiments (One and Two, Chapters 5 and 6 respectively), increased sAA was also observable in control participants as well stress participants, albeit for a shorter duration. It was postulated that this might have occurred as a result of anticipatory stress. However, it was also noted that sAA as a biomarker is incredibly sensitive and levels can also increase as a result of increased PNS activity, or occur from an interaction of SNS/PNS activity that amplifies sAA concentration (Bosch et al., 2011). In the present experiment, control participants were forewarned of their 'control' status in an attempt to minimise anticipatory stress. However, of equal importance is the fact that by measuring performance in the morning, variance in basal sAA level was also minimised. Similar to Cortisol, sAA follows a diurnal cycle where levels change over the course of the day. However, unlike Cortisol, sAA levels are lower and more stable in the morning before increasing later in the day (Nater et al., 2007). Therefore, it is possible that, in the same manner that afternoon testing offers the most stable period for measurement of cortisol, morning testing offers the most reliable period when considering sAA as a biomarker. This could not be confirmed conclusively however, as the experiment did not take additional measures of SNS activity, such as HR monitoring or skin conductance, which would help to support such a conclusion. Experiments One and Two recommended such an approach and moving forward it seems all the more important, as it could offer further support for the use of sAA, with the insight that it is a stable biomarker of stress when testing in the morning, perhaps more stable than Cortisol.

Previous experiments have noted gender differences in both cognition and physiology following exposure to stress (Hoskin et al., 2014; Kudielka & Kirschbaum, 2005; Verma et al., 2011). Indeed, Experiment Two highlighted gender differences and recommended the sampling of males and females separately in order to better understand those differences. Unfortunately, due to experimental constraints it was not possible to

collect a sufficiently powerful sample of exclusively males or females. However, the data showed that not only was flanker performance moderated by stress exposure, but that the effect was most greatly pronounced in males. In this case, whilst stress reduced the flanker effect, the absence of stress led to the flanker effect increasing. Despite presenting strong effect sizes (partial $\eta^2 = .67$, Cohens $d = 1$), the statistical power underlying this result was grossly disadvantaged by the small sample of 12 males. The present series of experiments have therefore highlighted the importance of conducting gender specific studies to understand the influence of stress, and stress-linked physiology on attention which should be the focus of any future work.

Similarly, both the selection of the ANT-R itself, and the use of split-halves has resulted in a greatly reduced number of trials, which has compromised the power of the results. This is particularly relevant to the current results as although the use of "split-halves" has been previously validated, the current data showed that split-half reliabilities for congruent trials was less than optimal. Therefore, observed changes to the executive control network, whereby the flanker effect was significantly altered post-manipulation, should be treated with caution. However, having now identified the networks that stress appears to influence, future work should aim to examine these networks with an improved design that employs a greater number of trials in order to ensure these results are not only replicable, but robust.

6.5.4 Conclusion

The present study investigated the effect of acute stress on attentional performance in the morning. The data show that experiments investigating stress can be successfully conducted in the morning, despite previous concerns regarding the influence of the Cortisol Awakening Response, provided performance is measured at least 105 minutes post-awakening. Further, the results offer support for both the initiation of a hypervigilant state following exposure to an acutely stressful psychosocial task, and the suppression of

practice effects which leads to less-optimal decision-making, in line with the previous experiment. An additional aim of the study was to explore the influence of stress-linked physiology on attentional performance. The results suggest that in the immediate aftermath of stress exposure, increased SNS reactivity, as indicated by higher levels of sAA, shares a relationship with alert performance and therefore may offer useful insight in stress research similar to that historically provided by Cortisol.

7 Conclusion

7.1 Chapter Overview

The primary intention of the empirical studies conducted throughout the present thesis was to investigate the effect of acute stress exposure on the functioning of the attentional networks. Previously, stress literature has limited its examination of attention to specified functions, such as the ability to focus or maintain attention. Yet the research also tends to employ numerous different tasks that are often less exacting and that require multiple aspects of attention to be engaged. Although these tasks might often be conceptualised as a 'selective' or 'divided' attention task, all draw on one or more elements of an individual's attentional network. Coupled with the wide range of stress-induction tasks available, and the variability in individual differences (e.g. age, working memory, magnitude of stress response), the results have provided an inconsistent view of the impact of stress on attention. It was anticipated that measuring the efficiencies of these attentional networks, in a single task would begin to provide a clearer picture of the impact of acute stress.

An additional intention of the thesis was to expand the physiological research that has been prevalent across stress literature for several decades. Physiological changes to biomarkers following stress such as heart rate, skin conductance, sAA and Cortisol are often presented as evidence for the successful induction of acute stress. However, whilst much work has implied that greater heart rate activity or increased Cortisol production leads to transformed cognition, very little work has examined the direct influence this change might convey. The present series of experiments therefore not only sought to use physiological biomarkers as evidence of stressed state, but also to explore the relationship between the magnitude of the physiological response and the size and direction of any changes to attentional efficiency.

As a synthesis of these aims, the efficiency of attentional functioning was measured following the stressor (or control task) in two time-points roughly aligned to known physiological responses; the Sympathetic Nervous System (SNS) which occurs immediately following stress and lasts for approximately 15 minutes (Herman & Cullinan, 1997), and the Hypothalamic Pituitary Adrenal (HPA) Axis which peaks approximately 20-30 minutes post-stress (Kirschbaum & Hellhammer, 1994). Previous literature that has investigated post-stress changes to cognition includes work that investigated change immediately following stress (Elling et al., 2011) or across prolonged periods (Olver et al., 2015). However, experimental designs often test across both periods (e.g. 0-60 minutes) without discriminating performance in one or the other. If physiological response does influence cognitive performance, the practice of measuring during individual periods of physiological activity could offer additional insight into the conflicted nature of the literature.

7.2 Results and Limitations

7.2.1 Design

7.2.1.1 Socially Evaluative Cold Pressor Task (SECPT)

Transactional models of stress highlight the importance of an individual's appraisal and response to environmental change (Hancock & Warm, 2003). For this reason, the experiments used the Socially Evaluative Cold Pressor Task (SECPT) to induce an acutely stressed state. In addition to the environmental change elicited by immersing a participant's hand in ice-cold water, the task employs a socially evaluative component whereby participants are led to believe their reaction to the task, and overall performance, is being critiqued against other participants. This leads to additional psychological stress and a more potent subjective and physiological response (Dickerson & Kemeny, 2004; Schwabe et al., 2008).

The results of the three experiments (and pilot study) supported this claim, as participants exposed to the SECPT demonstrated much greater self-reported measures of stress compared to those who experienced the warm water control task. Measures included higher levels of state anxiety and stress, greater perceptions of demand as well as lower ratings of their own performance. Furthermore, Experiments Two and Three provided clear evidence that experiencing the SECPT resulted in a significant increase in task-focused and emotion-focused coping, thus offering support for a transactional model of stress.

7.2.1.2 Biomarkers of Stress

Physiological biomarkers of salivary Alpha Amylase and Cortisol were also collected across the experiments, with each providing strong evidence for the induction of stress. Alpha Amylase production significantly increased in the immediate aftermath of the SECPT, whilst Cortisol production peaked approximately 20 minutes after the task. These results were in line with expectations (Dickerson & Kemeny, 2004; Rohleder et al., 2004). Physiological response was also a key consideration when selecting the appropriate stress task. With its rapid administration (~3 minutes), the SECPT allowed clear delineation of the early (SNS) and delayed (HPA-Axis) physiological response to stress, something that is not achievable with other common socially evaluative stressors, such as the Trier Social Stress Test (TSST - Kirschbaum, Pirke, & Hellhammer, 1993). Therefore, this permitted measurement of the attentional networks during periods more closely aligned with the physiological reactions to stress.

Cortisol is commonly collected throughout stress research to understand whether stress has been experienced. Importantly however, as Cortisol follows a diurnal cycle, with levels higher and more volatile in the morning, the majority of research has been performed in the afternoon. The results of Experiments Two and Three show some support for this, as baseline levels were much higher in the morning (5.7 nmol/l) than in

the afternoon (3.38 nmol/l). However, although Experiment Three was performed during the morning, it was outside of the known CAR window (~ 60 minutes) and therefore the results were unlikely to have been influenced by the CAR. Therefore, the results show that stressed performance can reasonably be measured in a morning experiment, offering an opportunity to gain a more complete understanding of how stress affects cognition throughout the day.

Whilst Cortisol is one of the most validated biomarkers employed in stress research, using sAA as a biomarker of stressed SNS activity is a relatively recent practice. Although Experiment 3 offered clear support for our hypothesis that sAA would increase following stress exposure, but not amongst controls, data from Experiments One and Two were less straightforward. In both, sAA levels increased for control participants, with one possible explanation being that participants experienced anticipatory stress (Robinson et al., 2013). Alternatively, some research has suggested that sAA has limited utility as a measure of SNS activity following stress, as sAA levels can also be influenced by increased PNS activity, an interaction of SNS/PNS activity that subsequently amplifies sAA level, or importantly, saliva flow rate (Bosch et al., 2011).

Across this programme of study, sAA was measured as total concentration (i.e. units per millimetre), yet others have recommended that sAA secretion rate, measured by dividing volume (weight) by the time taken to obtain the saliva sample, provides a better indication of SNS activity (Beltzer et al., 2010). However, in the three experiments described in the thesis this was not possible; although the majority of participants took two minutes to provide their saliva samples, there were limited instances when participants felt that the saliva swab was not saturated. In these instances, a small number of participants kept the salivette in their mouth for an additional period (usually up to 30 seconds). As these particular instances were not recorded, flow rate was impossible to accurately discern, meaning an opportunity was lost to gather a clearer understanding of the effects of stress on sAA activity.

Additionally, similar to Cortisol, sAA follows a diurnal cycle, albeit with higher levels later in the day, and lower, more stable levels in the morning. Experiments Two and Three supported this, with baseline sAA levels lower in the morning (97.75 u/ml), than in the afternoon (114.89 u/ml). However, the observation that SNS activity (greater sAA level) is related to attentional performance in the morning, but not the afternoon, could have been confounded by the fact that sAA is typically more stable in the morning than the afternoon.

Therefore, in future studies, it will be important to not only record additional measures of SNS activity (such as HR and skin conductance) to understand its influence on stressed cognition at different times of the day, but also measure the time taken to collect the saliva to allow flow rate can be considered. In the present studies, this potentially could have resulted in clearer observations of SNS activity in response to both the stress and control manipulations, and might therefore have eliminated the unexpected results in Experiments One and Two (increased sAA in controls).

7.2.1.3 Attentional Networks

The Attentional Network Theory proposed by Posner and Petersen (1990) establishes distinct networks for fundamental aspects of attention such as reacting to stimuli (alerting network), switching between stimuli (orienting network), or selecting salient information (executive control network). These networks are involved individually or cooperatively when attention is engaged. Although many common attention tasks are often identified as measuring a particular type of attention, many operationalise that attention in a contrasting manner. To illustrate, both the Psychomotor Vigilance Task (PVT) and the Sustained Attention to Response Task (SART) are generally referred to as measures of sustained attention or vigilance. However, whereas the PVT requires a response to an infrequent target, the SART requires the participant to withhold a cyclic response when they encounter a rare target amongst a series of distractors. Performance of

both tasks relies heavily on the alerting network, requiring a participant to respond quickly to a stimulus. However, it is likely that the SART is more reliant on the executive control network, as participants are required to make a rapid decision to inhibit their cyclic response action. Arguably, such divergence in how tasks are operationalised could explain the inconsistent nature of stress literature. For this reason, the Attentional Network Task – Revised (ANT-R) was selected (Fan et al., 2009).

7.2.1.4 The Attentional Network Task – Revised (ANT-R)

The ANT-R uses difference scores to scrutinise performance in multiple aspects of fundamental attention, such as validity and alerting effects, that are commonly used in other, more popular attention tasks (e.g. Posner Cueing Task). The ANT-R lasts approximately 28 minutes and comprises of four blocks, each with 72 trials (288 total) where the first two blocks are repeated. The intention of the experiments was to measure attentional network performance during two post-stress periods, the shortest of which lasts no more than 15 minutes (SNS – immediately post-stress). This meant that the ANT-R, in its original form, was too long. However, as the latter two blocks repeat the first two blocks (in the same trial order), the study used a split-half paradigm i.e. two blocks completed in the early period, and two blocks in the delayed period. The approach has been validated previously (Greene et al., 2008) and was systematically checked during each experiment by analysing split-half reliabilities of all participants baseline ANT-R performance. Analyses showed support for this approach as cue and flanker performance in the first two blocks of baseline ANT-R was consistently and significantly correlated to performance in the latter two blocks of baseline. One exception to this pattern was observed in Experiment Three, when congruent flanker performance (accuracy) was not significantly correlated ($r = .23$, $p = .147$). This indicated that the split-half reliability for

accurate flanker performance was low and therefore any result relating to the flanker effect in Experiment Three should be treated with caution.[8]

7.2.1.4.1 Limitations of the ANT-R

Despite its ability to measure multiple attentional networks in parallel and evidence supporting the split-half approach, other less favourable characteristics of the ANT-R must be considered. One concern is the range of potential effects offered by the ANT-R. In addition to the three network effects derived from the original ANT, 12 other effects are available to examine. These include inhibition of return, disengagement and orienting time as well as a range of network interaction effects. Although added to the ANT to account for interactions between the networks, this number of measures substantially increases the possibility of a Type I error during analysis. For this reason, only a small number of effects were examined throughout the experiments. The three original effects were included; the alerting benefit, the orienting effect (aka moving and engaging) and the flanker conflict. These effects have not only been extensively investigated using the ANT (and variants); they have also been used individually in various studies (Heitz & Engle, 2007; Marshall et al., 2016). Therefore, they were deemed to represent the most robust and reliable measures of attentional network functioning (see also Hedge, Powell, & Sumner, 2018). An additional measure, the validity effect, was also included. Previous work has explored valid orienting of attention post-stress (Ellenbogen et al., 2002; Larra, Pramme, Schachinger, & Frings, 2016; Laumann, Gärling, & Stormak, 2003), whilst the pilot study also indicated that the validity effect might be moderated by stress. Although the other measures were not examined as part of this thesis, the associated data is made available via the Open Science Framework, should others wish to explore it (see appendices).

[8] A change to the flanker effect was observed in Experiment Three and this is discussed in greater detail in the next section.

An additional concern of the ANT-R relates to the small number of trials used to calculate each measure, or difference score. To illustrate, each block contains 72 trials made up of 12 No Cue trials, 12 Double Cue trials, and 48 spatial trials (3:1 - valid to invalid). This means that a difference score can comprise of as little as 24 trials per block (e.g. alerting benefit = No Cue – Double Cue). Consequently, whilst baseline effects integrate four blocks and comprise a minimum of 96 trials per effect, those in the post-stress ANT-R which used split-halves are appreciably weaker. Certain effects (alerting benefit) are calculated using as few as 48 trials, thus power is substantially reduced. Nevertheless, several studies have verified the ANT-R and its variants reliably demonstrate these network effects, even with so few trials (Murphy & Alexopoulos, 2006; Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010; Posner et al., 2002; Weaver, Bédard, & McAuliffe, 2013). Additionally, effect checks were performed for each experiment to confirm the task was generating the expected effects. A series of 10 t-tests were performed for each experiment, examining each of the hypothesised effects (2 (split halves - 1 and 2) x 4 (effects) – RT; plus 2 t-tests for flanker effect (split halves - 1 and 2) – Accuracy). All effects were significant and in the hypothesised direction (all t's > 4.95, p's < .001, *Glass's* Δ > .78) (see Appendix E). This indicates that even though the smaller number of trials might have resulted in reduced power, the task itself was still sensitive enough to introduce the expected effects.

7.2.1.5 Gender differences

Finally, effects of gender were anticipated in the research. Gender differences have long been considered in stress research due to known differences in appraisal (Zandara et al., 2016) and physiology (Kirschbaum et al., 1999; Ordaz & Luna, 2012). Research trends toward male-dominated samples, most probably as a result of researchers' preference to use Cortisol as their measure for successful stress induction. As a hormone, Cortisol is heavily moderated by a female's menstrual cycle, as well as use of oral

contraceptives. Consequently, research examining stress amongst females faces additional challenges that must be accounted for (Kirschbaum et al., 1999). In the present series of experiments it was anticipated that the sample would largely comprise of females given the research was performed in a department with historically high numbers of female students (approx. 77 % in most recent publicly available figures - University of Southampton Diversity Report, 2010). Therefore, additional measures were implemented to minimise the impact, including testing females during the luteal phase of their menstrual cycle to ensure maximum Cortisol reactivity (Kudielka & Kirschbaum, 2005) and recording contraceptive use.

Given the demographics of the department where data collection took place, it was also acknowledged that collecting a wholly male sample would be difficult. Therefore, all three experiments used a mixed gender sample, with the expectation that any gender differences would be noted and identified as points of interest for future work, whilst being as representative as possible. The data from the experiments did provide evidence of gender differences and these are identified as avenues for future research.

7.3 Experiment One

Whilst Experiment One demonstrated both the efficacy of the SECPT as a stressor and the split-half approach, there was little evidence for the impact of stress on the attentional networks. Higher sAA level was observed to be weakly associated with a smaller alerting benefit during the delayed period of testing. However, this result was confounded by an atypical response from controls, who also exhibited high sAA despite no exposure to stress. This was concluded to result from anticipatory stress and led to a small procedural change in subsequent studies, with control participants informed prior to the task that their water would not be cold (see Table 7.1). Additional issues related to the experiments design and implementation also became apparent following Experiment One.

7.3.1 Practice and Fatigue

Whilst there appeared to be no effect of stress exposure to attentional network performance, overall performance showed susceptibility to the effects of practice and fatigue. This raised the possibility that any effect of stress might have been masked by control participants becoming more skilled, or subsequently tired from successive iterations of the task. As a result, Experiments Two and Three required participants to only complete one post-manipulation run of the ANT-R, either in the early or delayed period. This resulted in reduced practice whilst also meaning participants were less task-fatigued.

7.3.2 Time of Day

Contrary to common practice, testing for Experiment One was conducted both in morning and afternoon sessions. Researchers frequently conduct stress experiments exclusively during the afternoon to avoid a possible confounding effect of the Cortisol Awakening Response (CAR). As Cortisol is often employed as a validity check to ensure the effectiveness of the stressor, afternoon experiments reduce the likelihood of observing confounding (high) Cortisol levels among control participants. However, stress is experienced throughout the day, not just the afternoon, therefore the representativeness of any such research is reduced. Moreover, basal Cortisol is not stable throughout the day. Instead, its diurnal cycle means levels reduce steadily, with a nadir typically around midnight, before increasing during the latter sleep cycle (Kirschbaum & Hellhammer, 1989; Ross et al., 2014). If elevated Cortisol is not only a consequence of stress but also a precursor to, or driver of cognitive change, it stands that measuring at alternate times of day might elicit different effects upon cognition. Although the data from Experiment One showed no evidence for an effect of stress, it did indicate that the magnitude of attentional effects altered depending on time of day (e.g. participants in the morning exhibited a larger validity effect than those tested in the afternoon). Therefore, Experiment Two was limited

to an afternoon sample, whilst Experiment Three tested participants only in the morning. Additionally, Experiment Three also included fatigue measures (Karolinska Sleepiness Scale and time since awakening) to investigate the potential impact of performing the tasks soon after waking.

7.4 Experiment Two

Informed by the data from Experiment One, the second experiment tested participants exclusively in the afternoon and in only one post-manipulation period (early or delayed). The results showed strong support for both the efficacy of the stressor and the use of the ANT-R in a split-half procedure. Importantly, there was also evidence that exposure to stress moderated attentional network performance (see Table 7.1). Further, some of these appeared dependent upon the time course of stress, with changes apparent either during the early or the delayed periods.

7.4.1 Alerting Benefit

The data showed that whilst the alerting benefit was reduced for control participants in the early period, participants who had experienced acute stress exhibited a non-significant improvement. The decrease in control participant performance demonstrated a reduction in vigilance or sustained attention following two quick, successive runs of the ANT-R. However, when exposed to the SECPT, participants vigilance improved and effectively remained at baseline levels. This was in line with the original hypothesis which stated performance would be improved relative to controls.

7.4.2 Flanker Effect

Conversely, during the delayed period, participants exposed to stress demonstrated a reduced flanker effect, whereas it was maintained for control participants. Initially, this would appear to indicate a narrowing of attention, as reported previously by Chajut and Algom (2003). However, following examination of the discrete components of the flanker

effect, a more accurate explanation seems to be that stress led to the suppression of a practice effect.

7.4.3 The Validity Effect – Females

Irrespective of the post-manipulation period tested (early/delayed), the magnitude of the validity effect enlarged for females in the control group but remained at a similar level for stressed females. The data indicated this was a result of stressed females improved performance on invalidly cued trials, suggesting that stress-induced hypervigilance (see section 7.4.1) extended to improved reorienting of attention, but only for females.

7.4.4 Physiology and Attention

Finally, despite the evidence that exposure to stress led to strengthened physiological reactivity, and impacted performance on the ANT-R, there was little support for the hypothesis that stress-linked physiology directly influenced attentional performance.

7.5 Experiment Three

The third experiment was conducted exclusively in the morning. Notwithstanding the inclusion of a sleepiness scale and recording the time participants awoke, the procedure matched that of Experiment Two. The results offered the clearest evidence yet supporting the efficacy of the SECPT; self-reported stress measures were more extreme for all measures, whilst production of both sAA and Cortisol was again significantly increased. However, control participants did not demonstrate the anticipatory stress response observed in the earlier experiments. Indeed, control participants actually demonstrated a significant reduction in sAA level following the warm-water task. Analyses again showed strong support for the split-half design. One exception was congruent flanker trials (accuracy), which failed to demonstrated a significant correlation between the first split

half and the second. Importantly, although a difference was observed between stress and control participants for the flanker effect (accuracy), this was not limited to either the early or delayed period, meaning the split-half reliability is less important.

7.5.1 Alerting Benefit

The results showed that the alerting benefit reduced for stress participants but not controls, regardless of whether participants were tested in the early or delayed period (see Table 7.2). This appears to contradict the results observed in Experiment Two. However, closer examination of the components used to calculate the benefit did not support this. Instead, the effect once again appears to be driven by a hypervigilant state following stress. (The issue is discussed more fully in section 7.6.)

7.5.2 Flanker Effect

Stress was observed to impact the flanker effect. However, unlike Experiment Two, the effect increased in magnitude post-stress, whilst controls exhibited no change. Further, the difference was more pronounced amongst male participants as a result of male controls also demonstrating a diminished flanker effect. As with the alerting benefit, although the results of Experiments Two and Three appear to contradict each other, the nature of the change appears similar when exploring the components of the flanker effect. The reason for this is discussed below (see also section 1.5).

7.5.3 Physiology

The change to the alerting benefit following stress was directly supported by changes to stress-linked physiology. The data revealed that higher sAA level were estimated to share a significant relationship with a reduced alerting benefit. This would suggest that greater SNS activity following stress might influence attentional performance measured during the morning.

Table 7.1 *A summary of the hypothesised effects and observations across Experiment One to Three.*

Hypothesis One		
Exposure to the SECPT will result in greater levels of self-reported stress and higher coping, particularly task-focused coping.		
Experiment	**Supported**	**Evidence / Observed result**
1	Limited support	Participants reported significantly higher workload and stress, yet lower performance satisfaction than control participants. However, coping levels showed no group differences.
2	Yes	Participants reported significantly higher workload and stress, yet lower performance satisfaction than control participants. Greater levels of task-focused and emotion-focused coping following SECPT.
3	Yes	Participants reported significantly higher workload and stress, yet lower performance satisfaction than control participants. Greater levels of task-focused and emotion-focused coping following SECPT.
Hypothesis Two		
Exposure to the SECPT will produce typical physiological responses (increased sAA immediately; increased Cortisol approx. 20 minutes later).		
1	Yes	sAA significantly increased immediately after SECPT and Cortisol increased to peak 20 minutes post-SECPT.
2	Yes	sAA significantly increased immediately after SECPT and Cortisol increased to peak 20 minutes post-SECPT.
3	Yes	sAA significantly increased immediately after SECPT and Cortisol increased to peak 20 minutes post-SECPT.

Hypothesis Three		
Participants in the stress group will demonstrate enhanced alerting (RT) relative to controls, during both the early and delayed periods.		
1	No	There was no difference to the alerting benefit between stress and control participants.
2	Limited support	In the early period, controls vigilance reduced resulting in a smaller alerting benefit. Stress participants remained vigilant and maintained their alerting benefit. There was no difference in the delayed period.
3	Limited support	In the post-stress period (i.e. regardless of early/delayed), stress participants alerting benefit reduced due large improvements on both trial types (but particularly No cue trials). Controls exhibited much smaller improvements.
Hypothesis Four		
Participants in the stress group will demonstrate reduced validity effects (RT) relative to controls.		
1	No	There was no difference to the validity effect between stress and control participants.
2	Limited support	Following stress, females showed different validity effects compared to controls. The validity effect enlarged for controls, but maintained for stress as a result of stressed females improving performance on invalidly cued trials.
3	No	Baseline differences were observed but there were no observable difference following exposure to stress.
Hypothesis Five		
Participants in the stress group will demonstrate reduced orienting effects (RT) relative to controls.		
1	No	There was no difference to the orienting effect between stress and control participants.

2	No	There was no difference to the orienting effect between stress and control participants.
3	No	There was no difference to the orienting effect between stress and control participants.

Hypothesis Six		
Participants in the stress group will demonstrate a different flanker effect following stress, relative to controls.		
1	No	There was no difference to the flanker effect between stress and control participants.
2	Yes	Following stress, the flanker effect was reduced in the delayed period compared to controls as a result of a practice effect (observable in controls) being suppressed.
3	Yes	Following stress, the flanker effect was enlarged compared to controls as a result of a practice effect (observable in controls) being suppressed. The effect was more pronounced in males as controls also demonstrated a smaller flanker effect.

Hypothesis Seven		
Increased levels of sAA and Cortisol will be positively correlated with the behavioural attention changes identified above.		
1	Limited support	sAA was estimated to predict (albeit weakly) a smaller alerting benefit.
2	No	Neither sAA nor Cortisol predicted any attentional changes.
3	Yes	Higher sAA was estimated to predict a smaller alerting benefit, supporting the behavioural data.

7.6 The Issue of Difference Scores

The results reported for Experiment Three initially appear to contradict those of Experiment Two, as changes to the magnitude of both the alerting benefit and the flanker effect appear to reverse. This would suggest that the impact of stress on attention during the morning is distinctly different to the impact of stress in the afternoon. However, such a conclusion is likely mistaken, as it is heavily influenced by the ANT-Rs use of difference scores. Notwithstanding known criticisms of difference scores, such as their low reliability due to the inverse relationship between "difference score reliability and the correlation between the two variables used" (Salthouse & Seddon, 2002, cited in Macleod et al., 2010), their use across the present experiments highlights a key concern. When measuring difference scores across time-points, their magnitude can increase, decrease, or remain unchanged. However, there are several ways in which this can be achieved. To illustrate, the magnitude of an alerting benefit could be increased by; 1) response time slowing on No Cue trials, but little/no change on Double Cue trials, 2) RT showing little change on No Cue trials, but speeding on the Double Cue trials, or 3) RT slowing on No Cue trials whilst also speeding on Double Cue trials. To draw conclusions only on the basis of a change to the difference score is overly simplistic and may miss the underlying factor that is driving the change. Closer inspection of the underlying components for the effects observed in both Experiments Two and Three support this view.

7.6.1 Stress and Alerting

Regarding Alerting, in Experiment Two, control participants failed to demonstrate improved RT for Double Cue trials, whereas those in the stress group exhibited improvement in both Double Cue and No Cue trials. This suggests that exposure to acute stress caused participants to become hypervigilant and speed their responses, regardless of cue type; something that control participants were unable to do. However, during Experiment Three, participants in the control group did exhibit small improvements for

both No Cue and Double Cue trials. However, whilst stress participants again improved on both trial types, their improvement on No Cue trials was significantly greater than their improvement on Double Cue trials, and the improvement exhibited by controls. This implies that stress participants again exhibited much greater vigilance than controls, that led to speeded responding, and supports the conclusion from Experiment Two that exposure to stress results in hypervigilance.

Stress-induced hypervigilance is a familiar result across the literature (Henckens et al., 2012; Thayer & Brosschot, 2005; van Marle et al., 2009). The difference between the two experiments is borne from the fact that in the morning, controls exhibit vigilance improvements (likely resulting from naturally higher levels of alertness at this time of day) with the effect strengthened by exposure to stress. Conversely, afternoon performance suffers from a vigilance decrement that is eliminated by exposure to stress.

7.6.2 Stress and the Flanker Effect

Similarly, inspection of the changes to the flanker effect in Experiments Two and Three clarify the influence of stress. In Experiment Two, exposure to stress reduced the flanker effect. The original hypothesis suggested that a reduced flanker effect would result from a narrowing of attention, whereby participants improved on Incongruent trials by ignoring the incongruent distractors. However, the means for each trial type fail to support this view. Although stress improved performance for Incongruent trials, it was a much smaller improvement than control participants exhibited. Further, performance on Congruent trials showed almost no improvement, despite control participants showing improvement. Therefore, the reduced flanker effect was judged to result from stress exposure eliminating a practice effect that was observable in controls. In Experiment Three, despite the flanker effect increasing, the trial means continue to support this conclusion. The data show that whilst control participants accuracy improved for Incongruent trials and remained constant for Congruent trials (possibly due to a ceiling

effect ~ 98.28 %), accuracy was poorer for both trial types following stress. This data would not support a "broadening of attention" interpretation, as Congruent trial performance should not be disadvantaged. Instead, it appears that stress exposure eliminated the practice effect that was apparent for control participants.

The data show that drawing inferences based only on difference scores could lead to flawed conclusions. Instead, it is important that any future work that utilises difference scores also investigates the components used to calculated those differences. This will elucidate what is driving any change.

7.7 Physiology as a Predictor

7.7.1 Cortisol

Existing research often uses biomarkers to check the efficacy of any stressor, with Cortisol accepted as the gold standard. As expected, across the present series of experiments Cortisol consistently identified those who experienced stress from those who were in the control condition, by way of significantly elevated levels approximately 20 minutes post-stress. However, a further aim of the research was to understand whether increased physiological reactivity following stress was driving cognitive change, a point that has been implied before, but not empirically tested (Bourne Jr & Yaroush, 2003; Elzinga & Roelofs, 2005; Plessow et al., 2011; Smeets et al., 2006). Although there was no evidence in Experiment One, Experiment Two showed higher Cortisol was estimated to weakly predict an enlarged flanker effect. However, this did not support the behavioural data which showed that exposure to stress resulted in a reduced flanker effect. Data from Experiment Three also implied that elevated Cortisol was related to an increased validity effect, yet the behavioural data showed that participants who had been exposed to stress were no different to control participants.

The results show that increased levels of Cortisol are a useful and reliable predictor of stress, and offers further support to pre-existing literature. However, it seems that those

increases are infrequently associated with changes to attention, implying that higher Cortisol does not directly influence attention.

7.7.2 Alpha Amylase

Evidence for the influence of the SNS (measured using sAA) was more promising. Salivary Alpha Amylase continues to grow in popularity as it can be measured alongside Cortisol within a single saliva sample, and offers a good measure of SNS activity (Rohleder et al., 2006; van Stegeren et al., 2008). In both Experiment One and Two, control participants displayed small increases in sAA production, most likely as a result of anticipatory stress, highlighting the sensitivity of the measure. However, stress participants were still identifiable as they presented significant increases for longer durations than controls. In Experiment Three however, control participants exhibited a reduction in their sAA level whereas stress participants again exhibited typical significant increases. This result suggests that sAA, particularly in the morning, is as effective as Cortisol as a measure of stress.

Of further interest, in both Experiments One and Three, higher sAA production was associated with smaller alerting benefits. Experiment One behavioural data failed to support this result as there were no observed differences between control and stress participants (on the ANT-R). Further, any relationship would need to be approached with caution given the atypical control response (anticipatory stress increase). Importantly however, the finding was repeated for Experiment Three, where it was supported by the behavioural data that revealed participants exposed to stress exhibited a smaller alerting benefit. Therefore, not only did Experiment Three demonstrate the clearest support that physiological reactivity reflects stress state (i.e. increases to both sAA and Cortisol, at hypothesised time-points). It also showed that increased SNS activity (higher sAA production) following acute stress exposure in the morning shares a significant relationship with the magnitude of the alerting benefit. Consequently, the magnitude of the alerting

benefit might be directly influenced by sympathetic nervous system activity. These results offer a clear rationale for further exploring the relationship between SNS activity and attentional performance. However, as noted in the limitations of the thesis (and individual experiments), this would be greatly improved by considering other markers of SNS activity, as well as considering salivary flow rate when measuring sAA.

7.8 Future Work

Several directions for future research have emerged from the results. Practically, it appears that researchers should consider performing more studies in the morning, as the evidence suggests that performance can be measured successfully in the morning without the CAR influencing the results (provided measurement is performed outside of the known CAR window (~ 60 minutes post-awakening). Additionally, there was no observable relationship with attentional performance and time since awakening. Therefore, future work should be undertaken immediately to replicate the large body of afternoon studies to understand their applicability, if any, to stressed cognition in the morning.

Notwithstanding the sensitivity of sAA measurement, the experiments appear to highlight sAA as a suitable biomarker of stress, supporting earlier work (Nater et al., 2005; Skoluda et al., 2015; Skosnik et al., 2000). Data from Experiment Three (and potentially Experiment One) also imply that greater levels of SNS activity (higher sAA level) might affect vigilance. Therefore, it would be prudent to perform a replication of Experiment Three to confirm and understand the robustness of this relationship. Moreover, future studies exploring the psychobiology of stress on cognition should endeavour to both collect sAA (in addition to the typical Cortisol), and explore whether increased levels of SNS physiological activity share any relationship with the mode of cognition being measured.

The results of Experiments Two and Three demonstrated some familiar findings, including that stressed individuals move toward a hypervigilant state (Henckens et al.,

2012; van Marle et al., 2009). These were observed in a task that permits measurement across multiple networks and foci of attention, despite previous research tending to explore specific vigilance tasks. Notwithstanding the fact that a task that requires multiple elements of attention to be engaged offers greater representativeness to real-life tasks; such a task might actually draw out hitherto unidentified effects. Indeed, the suppression of a practice effects appears to be novel to research examining stressed attention, in spite of previous work exploring flanker performance. It is possible that such suppression is only induced, or at least identifiable, when individuals are required to allocate their resources to multiple components of a task. Therefore, future work might consider expanding the stress literature utilising tasks with multiple elements, similar to the ANT-R, rather than focusing on discrete aspects of cognition using highly specified tasks (e.g. the PVT). Development and testing of other such tasks might also substantiate the present findings, which suffered reduced power (small number of trials) owing to the use of an "off-the-shelf" task, rather than one specifically designed to rapidly test multiple aspects of attention (i.e. in the 15-minute periods required).

Finally, the data underscored the existing issue of gender effects, whilst also highlighting how they are moderated by the time-course of stress. Unfortunately, acknowledging these known gender differences, it has become convention for researchers to concentrate their efforts on one particular gender. The result is an undoubtedly broad and diverse body of research. However, there appear to be few, if any, studies that have found evidence for (or against) an effect in one gender, that has then performed the same study to explore that effect in the other gender. For the present experiments, although the samples were weighted more heavily toward females than males, both Experiments Two and Three demonstrated gender specific effects (validity effect and flanker effect respectively). Therefore, future research could elucidate gender differences and their relationship with stress if experiments are conceived as pairs of studies, or mixed-gender samples with enough power to investigate each separately.

7.9 Conclusion

The series of experiments examined the impact on the efficiency of attentional functioning following exposure to acute psychosocial stress. Individuals exposed to acute stress demonstrated significantly increased levels of vigilance (hypervigilance) compared to controls, that appeared to manifest slightly differently in the morning compared to the afternoon. This was possibly as a result of natural differences to vigilance level at alternate times of the day. Moreover, although hypervigilance was observable immediately and relatively short-term during the afternoon, it appeared more pervasive and longer lasting when participants were tested in the morning.

Additionally, whilst control participants demonstrated a practice effect (i.e. the ability to learn from their previous ANT-R) and thus improved their performance on the executive control component of the ANT-R, the practice effect was suppressed in those who had experienced acute stress. This might suggest an impairment to their ability to learn under stress, but requires more empirical work. The effect was prevalent during both the morning and afternoon sessions. However, in the afternoon the effect appeared to be moderated by the time-course of stress, as it was only observable 20-35 minutes post-stressor and not in the immediate aftermath.

Concerning the physiology of stress, the experiments offer further support for the use of salivary Alpha Amylase and Cortisol as biomarkers of stressed state. Nevertheless, despite the importance placed on Cortisol by researchers and intimations that it might be directly responsible for changes to cognition, the data show little support for this. However, preliminary evidence was observed that suggests increased SNS activity post-stress, as evidence by higher sAA level, might share a relationship with cognitive change, specifically vigilant attention and should be considered in future empirical work.

Appendix A

Pilot study data and statistical tests/output have been uploaded to the Open Science Framework and can be viewed at the following link

https://osf.io/ubqcy/?view_only=7997091e9c9748d4bcb10771546a0c60

Appendix B

Copies of the questionnaire scales completed by participants.

Karolinska Sleepiness Scale

STUDY: Examining the effects of socially evaluative pressor tasks on attention.

What time did you wake up this morning?

_____

SUBJECTIVE SLEEPINESS

Please, indicate your sleepiness during the 5 minutes before this rating by circling the appropriate description

1 = extremely alert
2 = very alert
3 = alert
4 = rather alert
5 = neither alert nor sleepy
6 = some signs of sleepiness
7 = sleepy, but no effort to keep awake
8 = sleepy, some effort to keep awake
9 = very sleepy, great effort to keep awake, fighting sleep

Ppt ID _____
Date _____

T1

Spielberger Trait Anxiety Index (STAI)

STUDY: Examining the effects of socially evaluative pressor tasks on attention.

STAI

INSTRUCTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and circle the appropriate number to the right of the statement to indicate how you **generally** feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

		Not at all	Somewhat	Moderately so	Very much so
1)	I feel pleasant	1	2	3	4
2)	I feel nervous & restless	1	2	3	4
3)	I feel satisfied with myself	1	2	3	4
4)	I wish I could be as happy as others seem to be	1	2	3	4
5)	I feel like a failure	1	2	3	4
6)	I feel rested	1	2	3	4
7)	I am 'calm, cool and collected'	1	2	3	4
8)	I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
9)	I worry too much over something that doesn't really matter	1	2	3	4
10)	I am happy	1	2	3	4
11)	I have disturbing thoughts	1	2	3	4
12)	I lack self-confidence	1	2	3	4
13)	I feel secure	1	2	3	4
14)	I make decisions easily	1	2	3	4
15)	I feel inadequate	1	2	3	4
16)	I am content	1	2	3	4
17)	Some unimportant thought runs through my mind and bothers me	1	2	3	4
18)	I take disappointments so keenly that I can't put them out of my mind	1	2	3	4
19)	I am a steady person	1	2	3	4
20)	I get in a state of tension or turmoil as I think over my recent concerns and interests.	1	2	3	4

Ppt ID_____

Date_____

T1

Intolerance of Uncertainty Scale (IUS-12)

STUDY: Examining the effects of socially evaluative pressor tasks on attention.

IUS-12

INSTRUCTIONS: Please circle the number that best corresponds to how much you agree with each item.

	Not at all characteristic of me	A little characteristic of me	Somewhat characteristic of me	Very characteristic of me	Entirely characteristic of me
12. Unforeseen events upset me greatly.	1	2	3	4	5
2. It frustrates me not having all the information I need.	1	2	3	4	5
3. Uncertainty keeps me from living a full life.	1	2	3	4	5
4. One should always look ahead so as to avoid surprises.	1	2	3	4	5
5. A small unforeseen event can spoil everything, even with the best of planning.	1	2	3	4	5
6. When it's time to act, uncertainty paralyses me.	1	2	3	4	5
7. When I am uncertain I can't function very well.	1	2	3	4	5
8. I always want to know what the future has in store for me.	1	2	3	4	5
9. I can't stand being taken by surprise.	1	2	3	4	5
10. The smallest doubt can stop me from acting.	1	2	3	4	5
11. I should be able to organize everything in advance.	1	2	3	4	5
12. I must get away from all uncertain situations.	1	2	3	4	5

Ppt ID _____

Date _____

T1

National Aeronautics and Space Administration - Task load Index (NASA-TLX)

STUDY: Examining the effects of socially evaluative pressor tasks on attention.

NASA - TLX

INSTRUCTIONS: Please indicate, by placing a mark (| or X) on the scale how you feel at this moment in time, having completed the task.

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Very Low — Very High

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated and annoyed were you?

Very Low — Very High

Stress — How stressed did you feel?

Very Low — Very High

Ppt ID_____

Date_____

T1

Spielberger State Anxiety Index (SSAI)

STUDY: Examining the effects of socially evaluative pressor tasks on attention.

SSAI

INSTRUCTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and circle the appropriate number to the right of the statement to indicate how you **feel** right **now**, that is at **this moment**. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

		Not at all	Somewhat	Moderately so	Very much so
1)	I feel calm.....	1	2	3	4
2)	I feel secure.....	1	2	3	4
3)	I am tense.....	1	2	3	4
4)	I feel strained.....	1	2	3	4
5)	I feel at ease.....	1	2	3	4
6)	I feel upset.....	1	2	3	4
7)	I am presently worrying over possible misfortunes.....	1	2	3	4
8)	I feel satisfied.....	1	2	3	4
9)	I feel frightened.....	1	2	3	4
10)	I feel comfortable.....	1	2	3	4
11)	I feel self-confident.....	1	2	3	4
12)	I feel nervous.....	1	2	3	4
13)	I am jittery.....	1	2	3	4
14)	I feel indecisive.....	1	2	3	4
15)	I am relaxed.....	1	2	3	4
16)	I feel content.....	1	2	3	4
17)	I am worried.....	1	2	3	4
18)	I feel confused.....	1	2	3	4
19)	I feel steady.....	1	2	3	4
20)	I feel pleasant.....	1	2	3	4

Ppt ID _____

Date _____

T2

Coping Inventory for Task Stress – Situational (CITS-S)

CITS

INSTRUCTIONS: Think about how you dealt with any difficulties or problems that arose while you were performing the pressor task you have just performed. Below are listed some options for dealing with problems such as poor performance or negative reactions to doing the task. Please indicate how much you used each option, specifically as a deliberately chosen way of dealing with problems. To answer circle one of the following answers:

Not at all = 0 A little bit = 1 Somewhat = 2 Very much = 3 Extremely = 4

I ...

1.	Worked out a strategy for successful performance	0	1	2	3	4
2.	Worried about what I would do next	0	1	2	3	4
3.	Stayed detached or distanced from the situation	0	1	2	3	4
4.	Decided to save my efforts for something more worthwhile	0	1	2	3	4
5.	Blamed myself for not doing better	0	1	2	3	4
6.	Became preoccupied with my problems	0	1	2	3	4
7.	Concentrated hard on doing well	0	1	2	3	4
8.	Focused my attention on the most important parts of the task	0	1	2	3	4
9.	Acted as though the task wasn't important	0	1	2	3	4
10.	Didn't take the task too seriously	0	1	2	3	4
11.	Wished that I could change what was happening	0	1	2	3	4
12.	Blamed myself for not knowing what to do	0	1	2	3	4
13.	Worried about my inadequacies	0	1	2	3	4
14.	Made every effort to achieve my goals	0	1	2	3	4
15.	Blamed myself for becoming too emotional	0	1	2	3	4
16.	Was single-minded and determined in my efforts to overcome any problems	0	1	2	3	4
17.	Gave up the attempt to do well	0	1	2	3	4
18.	Told myself it wasn't worth getting upset	0	1	2	3	4
19.	Was careful to avoid mistakes	0	1	2	3	4
20.	Did my best to follow the instructions for the task	0	1	2	3	4
21.	Decided there was no point in trying to do well	0	1	2	3	4

Ppt ID _____

Date _____

T4

Appendix C

Experiment One data and statistical tests/output have been uploaded to the Open Science Framework and can be viewed at the following link

https://osf.io/ubqcy/?view_only=7997091e9c9748d4bcb10771546a0c60

Appendix D

Experiment Two data and statistical tests/output have been uploaded to the Open Science Framework and can be viewed at the following link

https://osf.io/ubqcy/?view_only=7997091e9c9748d4bcb10771546a0c60

Appendix E

Experiment Three data and statistical tests/output have been uploaded to the Open Science Framework and can be viewed at the following link

https://osf.io/ubqcy/?view_only=7997091e9c9748d4bcb10771546a0c60

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