The Effects of Acute Stress on Learning and Decision Making

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Abstract

The current body of literature pertaining to the effects of acute stress on learning and decision making is limited. Research has found that acute stress can impact either positively or negatively on learning and decision making. The aim of the following study was to further expand on the effects of acute stress on learning, reversal learning and decision making. Participants (N = 40) were required to complete the State Scale of the State Trait Anxiety Inventory (STAI) in order to assess their stress reactivity, as this has frequently been overlooked in previous studies. In order to assess the potential effects of inducing acute stress on learning, reversal learning and decision making, participants completed two tasks that required them to learn stimulus-response mappings and make rapid decisions based on their acquired knowledge. One of the tasks was completed under threat of sudden bursts of unpleasant noise, while the other was completed in safe conditions. The results suggest that there is no difference in learning or reversal learning between stress responders and non-responders. However, contrary to previous research, stress was found to significantly enhance reversal learning in both responders and non-responders. Further exploratory analyses revealed that stress responders had significantly increased reaction times, when making high conflict decisions during the threat condition. In contrast, non-responders had significantly decreased reaction times. These findings indicate a relationship between acute stress and reversal learning and decision making. In addition, the findings provide insight into how individuals may differ in their application of knowledge while under stress, depending on whether they react to the stress manipulation.

Keywords: Acute Stress, Anxiety, Decision Making, High Conflict; Decisions, Learning, Non-Responders, Responders, Reversal Learning, State Anxiety, Threat Condition.

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and, to the best of my knowledge, this thesis contains no materials previously published except where due reference is made. I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying,

Signature

June, 2019

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The Effects of Acute Stress on Learning and Decision Making

1 Introduction

Since time immemorial it has been necessary for human beings to learn and make decisions. Humans are often required to learn and make decisions while in stressful circumstances (Porcelli, Lewis, & Delgado, 2012; Raio, Hartley, Orederu, Li, & Phelps, 2017). Throughout one's lifespan necessity often dictates making both high and low conflict decisions while in safe or threat conditions (Frank & Kong, 2008; Porcelli et al., 2012; Raio et al., 2017). Low-conflict decisions involve relatively easy choices as one option results in considerably better consequences than the alternatives (Frank, Samanta, Moustafa, & Sherman, 2007; Frank & Kong, 2008). High conflict decisions, however, involve more difficult choices as different options result in similar consequences (Frank et al., 2007; Frank & Kong, 2008). The process whereby this occurs is essential in order to suitably react and adapt to potentially safe or threatening environments (Cavanagh, Frank, & Allen, 2010; Raio et al., 2017).

Research suggests that learning and decision making differ in threatening conditions compared to safe conditions (Frank & Kong, 2008; Porcelli et al., 2012; Raio et al., 2017). Furthermore, research has suggested that stress has a curvilinear relationship with learning and decision making (Cavanagh et al., 2010; Ossewaarde et al., 2011; Salehi, Cordero, & Sandi, 2010; Starcke & Brand, 2012; Teigen, 1994). This implies that learning and decision making initially improves under stress conditions (Cavanagh et al., 2010; Salehi et al., 2010; Starcke & Brand, 2012; Teigen, 1994). However, increasing stress levels beyond the optimal point relative to task difficulty is detrimental (Cavanagh et al., 2010; Salehi et al., 2010; Starcke & Brand, 2012; Teigen, 1994).

The omnipresence of acute stress throughout the lifespan and the inability to correctly respond to safe or threatening environments is indicative of anxiety, depression and trauma-related disorders, while potentiating addictive behaviour (Berghorst, Bogdan, Frank, & Pizzagalli, 2013; Bogdan & Pizzagalli, 2006; Frank & Kong, 2008; Kumar et al., 2014; LeBlanc, 2009; Mather & Lighthall, 2012; Nikolova, Bogdan, Brigidi, & Hariri, 2012; Ossewaarde et al., 2011; Porcelli et al., 2012; Raio et al., 2017; Robinson, Overstreet, Charney, Vytal, & Grillon, 2013; Shafiei et al., 2012). The serious nature of these disorders, and their potentiation for maladaptive behaviour in stress vulnerable individuals warrants greater research (Berghorst et al., 2013; Cavanagh et al., 2010; Chrousos, 1998; LeBlanc, 2009; Mather & Lighthall, 2012; Raio et al., 2017; Robinson et al., 2013). It is therefore essential that further research is conducted to discern the effects of acute stress on learning and decision making, in order to predict and potentially improve health outcomes.

The inability to respond appropriately to safe or threating situations could result from acute stress affecting dopamine (DA) levels in the brain (Berghorst et al., 2013; Mather & Lighthall, 2012; Ossewaarde et al., 2011; Shafiei et al., 2012). The neurotransmitter DA is involved in synaptic neuroplasticity that supports learning and decision making (Cavanagh et al., 2010; Doll & Frank, 2009; Frank & Kong, 2008; Mather & Lighthall, 2012; Ossewaarde et al., 2011). These processes underlying learning and decision making occur in the basal ganglia (BG) (Doll & Frank, 2009; Frank & Claus, 2006; Frank & Kong, 2008; Mather & Lighthall, 2012; Schroll & Hamker, 2013). Hence, it is thought that acute stress influences learning and decision making by altering DA neurotransmission in the BG (Berghorst et al., 2013; Doll & Frank, 2009; Frank & Kong, 2008; Mather & Lighthall, 2012; Ossewaarde et al., 2011; Schroll & Hamker, 2013; Shafiei et al., 2012).

The finite body of research pertaining to the effects of acute stress on learning and decision making is inconsistent and has produced inconclusive results (LeBlanc, 2009; Lighthall et al., 2011; Porcelli et al., 2012; Raio et al., 2017; Shafiei, Gray, Viau, & Floresco, 2012; Starcke & Brand, 2012). This may be a consequence of the complexity of the neural pathways in the BG and individual differences in response to acute stress (Schroll & Hamker, 2013). The present study intends to further assess the effects of acute stress on learning and decision-making in safe contrasted to threat conditions. Learning and decision-making ability will be assessed with a probabilistic stimulus selection task (PSST). This study will also use an appropriate anxiety measure to assess individual differences in stress reactivity, since such individual differences have been shown to moderate the influence of stress on learning (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006).

The present study will examine the mechanisms of stress and in particular acute stress; the relationship between acute stress and learning; the relationship between acute stress and decision making; and whether these relationships depend on stress reactivity (as assessed via changes in state anxiety).

1.1 Defining Stress and Acute Stress

Research conducted on stress has resulted in a range of models and theories to assess and define stress as a concept (Mark & Smith, 2008). This has resulted in various definitions of different types of stress without consensus (Mark & Smith, 2008). The following dissertation shall utilise the general adaptation syndrome (GAS) model as proposed by Hans Selye (LeBlanc, 2009). Selye defined stress as an organism's subjective physiological or psychological response to stressors or stimuli (LeBlanc, 2009; Szabo, Tache, & Somogyi, 2012; Van Gemmert & Van Galen, 1997). Stress occurs in an organism's response to stimuli when greater exertion is

required for goal acquisition and maintenance. That is, if subjective psychological and physiological demands are evaluated as exceeding cognitive, emotional or physical resources, then the condition is referred to as a threat (Chrousos, 1998; LeBlanc, 2009; Van Gemmert & Van Galen, 1997).

The first stage of the GAS model is most pertinent to acute stress and is referred to as the alarm phase (Kim, Guy, Manocha, & Lin, 2012; LeBlanc, 2009; Neylan, 1998). Acute stress can be defined as the initial cognitive and bodily response after the sudden identification of a perceived threat (Chrousos, 1998; LeBlanc, 2009; Neylan, 1998). Acute stress results in the individual's appraisal of effort required to face the threat condition (Chrousos, 1998; LeBlanc, 2009). Moreover, acute stress results in adaptive behavioural and physical responses for successful adaptation to the observed state of threat (see Figures 1 and 2; Chrousos, 1998).

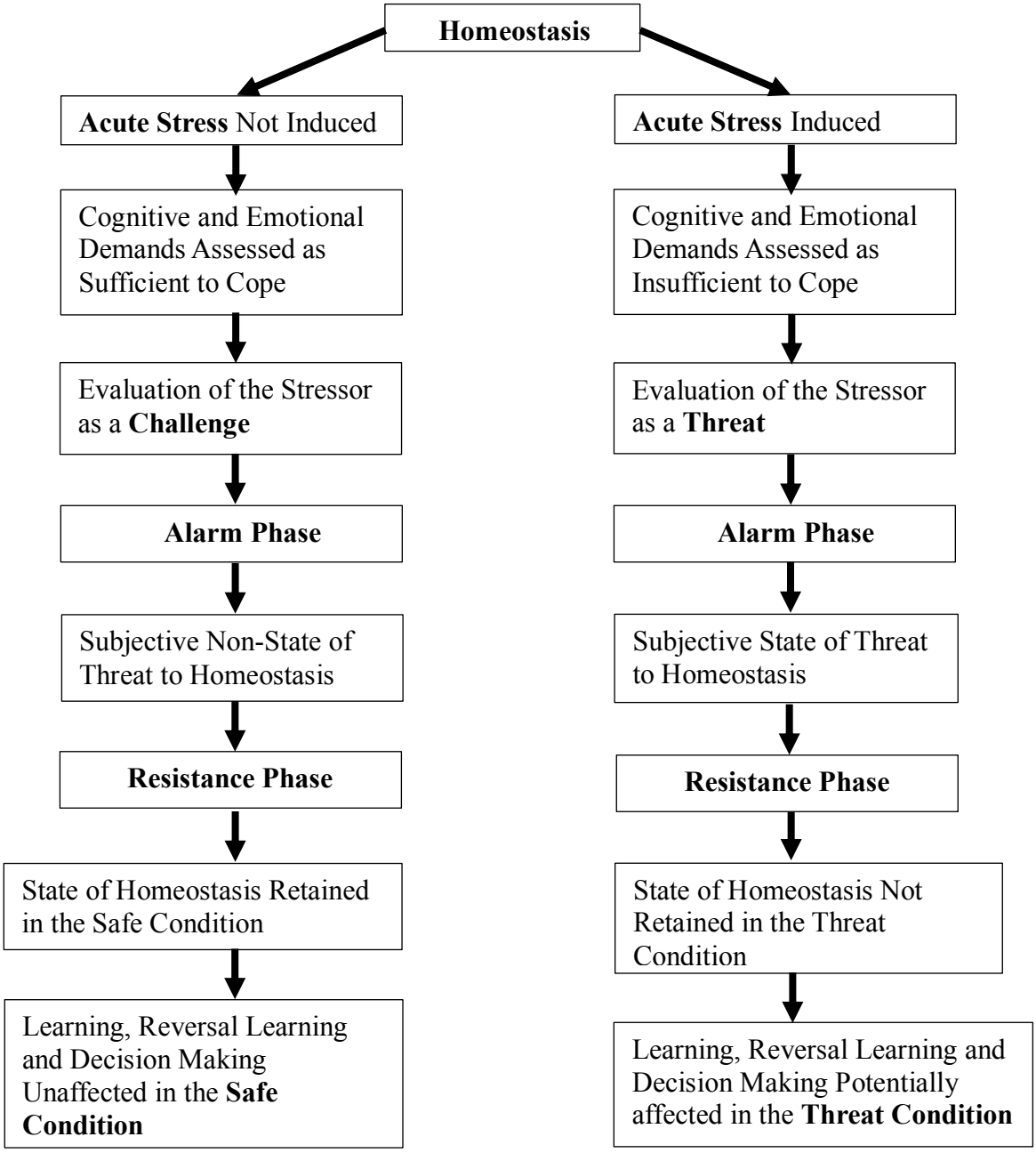

Figure 1. The conceptualisation of stress in the present thesis. Figure adapted from (Kim et al., 2012; Neylan, 1998; Szabo et al., 2012).

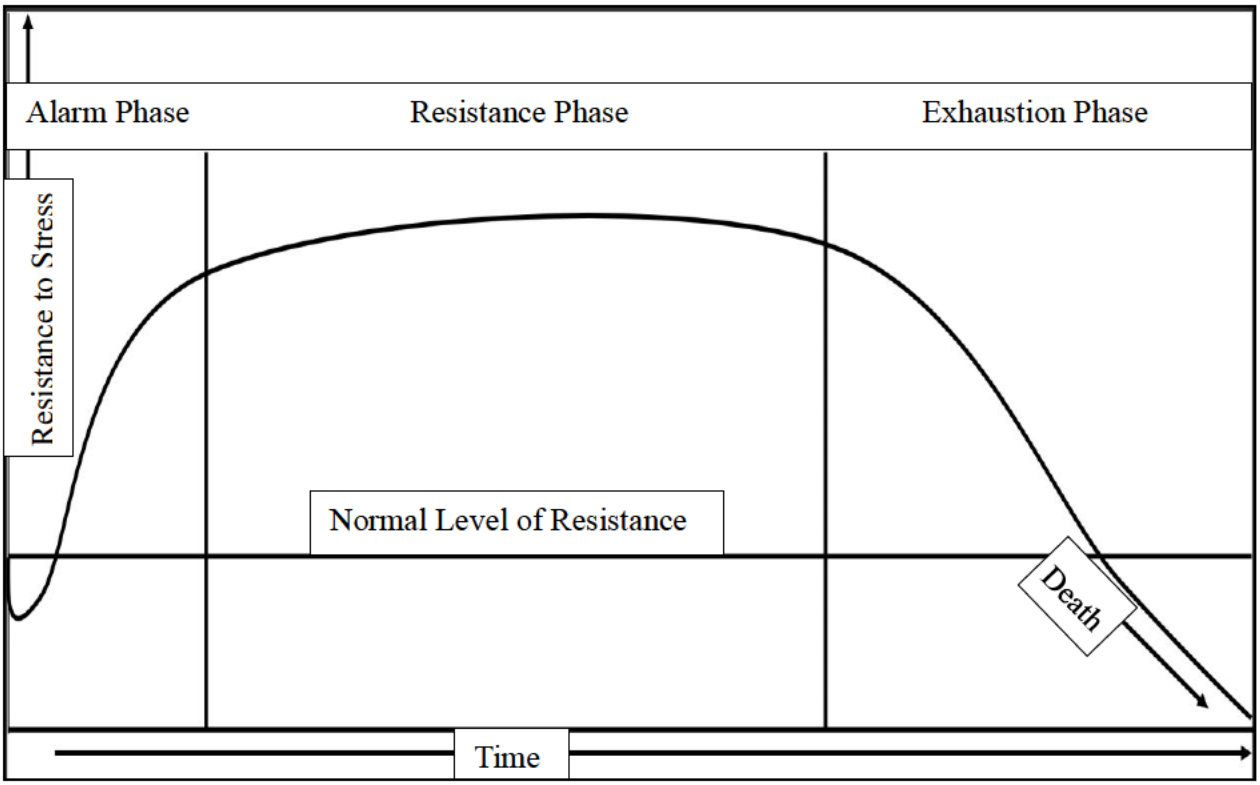

Figure 2. The conceptualisation of the GAS model in the present thesis. Figure adapted from (Kim et al., 2012; Neylan, 1998; Szabo et al., 2012).

1.2 The Relationship Between Stress and Anxiety

The present study will use state anxiety to evaluate stress reactivity, given that previous research has demonstrated that anxiety is associated with stress reactivity (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Goette, Bendahan, Thoresen, Hollis, & Sandi, 2015; Salehi et al., 2010; Starcke & Brand, 2012). Furthermore, anxiety has been found to have the same curvilinear relationship with learning and decision making as stress (Keeley, Zayac, & Correia, 2008; Preston, Buchanan, Stansfield, & Bechara, 2007; Salehi et al., 2010; Teigen, 1994). Moreover, research has discovered significant neurological crossover between the neural underpinnings of stress and anxiety (Lukasik, Waris, Soveri, Lehtonen, & Laine, 2019). This justifies using the

state scale of the state trait anxiety index (STAI-S), as an appropriate measure to disassociate stress responders and non-responders (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983).

1.2.1 Defining Anxiety

Anxiety can be defined as a negative affective state in response to stressors that are perceived as a threat to the attainment and continuance of a desired goal (LeBlanc, 2009; Schabracq, Winnubst, & Cooper, 2003). Moreover, anxiety can be described as the hyperarousal of the stress system in humans and animals (Chrousos, 1998; LeBlanc, 2009). Furthermore, anxiety is characterised by intensified states of awareness associated with amplified sensitivity in response to conflict, or a lack of certainty (Lukasik, Waris, Soveri, Lehtonen, & Laine, 2019). This has implications for decision-making, as decisions often involve a degree of uncertainty and perceived internal conflict when choosing between different alternatives.

1.2.2 Previous Studies Investigating the Relationship Between Stress and Anxiety

The bulk of research linking stress and anxiety have found significant correlations between the two variables (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Goette et al., 2015; LeBlanc, 2009; Lukasik et al., 2019; Salehi et al., 2010; Schabracq, Winnubst, & Cooper, 2003; Starcke & Brand, 2012). Previous research has measured both state and trait anxiety in order to assess stress reactivity (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Goette et al., 2015; Salehi et al., 2010; Starcke & Brand, 2012). The evidence suggests that individuals with significantly higher anxiety have greater subjective stress reactivity (Berghorst et al., 2013; Goette et al., 2015, Salehi et al., 2010; Starcke & Brand, 2012). Moreover, research demonstrates that stress responders report higher state anxiety following a stressor (Berghorst et al., 2013; Preston et al., 2007; Salehi et al., 2010; Starcke & Brand, 2012).

For example, Preston et al., (2007) when investigating the effects of anticipatory stress on decision making in a gambling task, utilised the STAI state and trait scales when contrasting experimental and control participants. In response to the induced stressor of giving a speech, the experimental group had higher heart rates and significantly increased self-reported state anxiety (Preston et al., 2007). This increase in state anxiety was further supported by Berghorst et al.'s (2013) experiment on acute stress and its effects on reward sensitivity. In addition to cortisol levels, the experimenters used self-reported state anxiety levels before and after an initial electric shock (Berghorst et al., 2013). The stress responder group reported a significant increase in state anxiety after the initial electric shock (Berghorst et al., 2013). Thus, these studies demonstrate that changes in self-reported state anxiety can successfully identify stress-reactive individuals.

1.2.3 Limitations of Previous Research

Several studies have only assessed trait anxiety in order to disassociate stress responders from non-responders (Goette et al., 2015; Starcke & Brand, 2012). This is a clear limitation as acute stress should temporarily affect an individual's state anxiety, while trait anxiety scales presumably measure a relatively stable tendency to feel anxious (Goette et al., 2015). Furthermore, trait anxiety does not necessarily indicate that a stress response will occur in threat conditions (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). This experiment shall address this issue via employing the state anxiety scale (STAI-S) of the State Trait Anxiety Inventory (STAI). Furthermore, most experiments did not assess state anxiety before and after the threat conditions (Goette et al., 2015; Starcke & Brand, 2012). Additionally, Bogdan and Pizzagalli (2006) conflated participants into one group without using the state scale STAI-S to disassociate stress responders from non-responders. These limitations shall be overcome with participants completing the state scale STAI-S before and after the safe and threat conditions

(Berghorst et al., 2013; Starcke & Brand, 2012). The participant's changes in their STAI-S scores will be used to disassociate stress responders from non-responders (Berghorst et al., 2013; Starcke & Brand, 2012).

1.3 Defining Learning and Reversal Learning

Learning can be defined as the habitual retention of appropriate responses that are followed by appetitive stimuli and the decline in responses that are followed by aversive stimuli (Epstein, Hurley, & Taber, 2018; Frank & Claus, 2006; Robinson et al., 2013; Teigen, 1994; Xiao, 2018). Moreover, learning is the short and long-term adaptation in the utilisation of information processing structures (Van Gemmert & Van Galen, 1997). Contrariwise, reversal learning is the adaptive updating of stimulus or response preferences with shifting reinforcement contingencies, for example, when a previously non-rewarded response is now rewarded (Epstein et al., 2018; Frank & Claus, 2006; Raio et al., 2017). In aversive reversal learning a former safe or threat signal is inversely coupled with the opposite safe or threat value (Epstein et al., 2018; Raio et al., 2017). This results from the safe or threat value being coupled with the opposite biologically salient outcome (Epstein et al., 2018; Raio et al., 2017). Reversal learning can be used to assess an individual's behavioural flexibility, and their ability to adaptively update their behaviour in response to shifting sources of threat (Raio et al., 2017).

1.4 The Relationship Between Learning and Decision Making

The current study is additionally focused on the relationship between learning and decision making. Research has demonstrated that learning and decision making both require activity within the BG and the orbitofrontal cortex (OFC) (Doll & Frank, 2009; Frank & Kong, 2008; Frank, Samanta, Moustafa, & Sherman, 2007; Otto, Raio, Chiang, Phelps, & Daw, 2013; Preston et al., 2007). Damage to these areas of the brain can result in impaired learning and

decision-making deficiencies (Frank & Claus, 2006). Thus, the evidence would suggest a neural connection between learning and decision making within the aforementioned parts of the brain (Frank & Claus, 2006). This is not surprising, given that decisions regarding which course of action to take involves weighing the consequences of alternative actions, which have generally been learnt.

1.4.1 Defining Decision Making

Decision making can be defined as the conscious or unconscious behaviour resulting from reinforced associations and neurobiological learning stratagems (Hikosaka, 2010; Lighthall, Gorlick, Schoeke, Frank, & Mather, 2013; Otto et al., 2013; Xiao, 2018). This intended or automated behaviour results from the evaluation of previous learning (Hikosaka, 2010; Lighthall et al., 2013; Otto et al., 2013; Xiao, 2018). Moreover, an individual's decisions will likely be the consequence of observed probability of positive or negative outcomes that follow different actions (Lighthall et al., 2013; Xiao, 2018).

1.4.2 The Relationship Between Acute Stress and Decision Making

The present study is furthermore interested in the relationship between acute stress and decision making. Decision making often occurs during stressful circumstances and difficult decisions are often inducive of stress (Mather & Lighthall, 2012; Porcelli et al., 2012; Simonovic, Stupple, Gale, & Sheffield, 2016; Starcke & Brand, 2012). Research has demonstrated that acute stress impacts decision making in both animals and humans (Goette et al., 2015; Mather & Lighthall, 2012). Moreover, it has also been found that acute stress increases risk taking in males, yet decreases risk taking in females when making decisions (Lighthall et al., 2011; Porcelli et al., 2012). While substantial research supports that the effects of acute stress on decision making vary, evidence suggests that there is potentially an optimal level of stress for

advantageous decision making (Arnsten & Goldman-Rakic, 1998; Kim et al., 2012; Starcke & Brand, 2012; Teigen, 1994). This might therefore support a curvilinear relationship between stress and decision making (Starcke & Brand, 2012).

The majority of research clearly suggests that acute stress has the potential to affect decision making (Shafiei et al., 2012; Starcke & Brand, 2012). These effects are potentially the result of acute stress increasing DA levels in the striatum, which is part of the BG, and the OFC (Mather & Lighthall, 2012; Starcke & Brand, 2012). These increases in DA often coincide with increases in cortisol levels in response to stressors (Mather & Lighthall, 2012). It is therefore evident that acute stress and decision making are neurologically and hormonally interwoven (Berghorst et al., 2013; Kim et al., 2012; Mather & Lighthall, 2012).

1.4.3 Previous Studies Investigating the Relationship Between Acute Stress and Decision Making

Considerable laboratory research supports that acute stress can potentially impair decision making in both animals and humans (Otto et al., 2013; Shafiei et al., 2012; Starcke & Brand, 2012). Several laboratory studies support that acute stress affects mental processes (e.g., adjustment from automated response, feedback processing, reward and punishment sensitivity and strategy use) (Shafiei et al., 2012; Starcke & Brand, 2012). These changes in function, however, might be advantageous or disadvantageous relative to the task and condition (Arnsten & Goldman-Rakic, 1998; Shafiei et al., 2012; Steinhauser, Maier, & Hübner, 2007; Starcke & Brand, 2012). Several studies did consistently observe that acute stress could result in increased reaction times, suggestive of increased caution when making decisions (Berghorst et al., 2013; Lighthall et al., 2011; Mather & Lighthall, 2012; Shafiei et al., 2012; Starcke & Brand, 2012; Steinhauser et al., 2007; Van Gemmert & Van Galen, 1997). In Shafiei et al.'s (2012) study

investigating the impact of acute stress on selective alterations in cost-benefit decision making, it was observed that acute stress resulted in increased decision latencies in rats.

Research on human participants has yielded similar results. In Van Gemmert and Van Galen's (1997) study, cognitive stressors were demonstrated to lead to significantly increased reaction times in human subjects. This finding was further supported by Berghorst et al. (2013), who found that acute stress selectively reduced reward sensitivity but only in individuals who reacted to the stress manipulation, whereby the stress reactive group exhibited significantly slower reaction times. Inversely, the no stress group were found to be significantly faster in their decision making (Berghorst et al., 2013). These findings were also partially supported in Lighthall et al.'s (2011) experiment that found gender differences in reward-related decision processing under stress, whereby human female participants were found to have significantly slower decision speeds. In contrast to female subjects however, male participants were inclined to have a marked increase in reaction speed (Lighthall et al., 2011; Mather & Lighthall, 2012). The findings of the aforementioned studies could suggest that an individual's stress reactivity might account for the way individuals respond to acute stress when making high conflict decisions (Berghorst et al., 2013; Shafiei et al., 2012; Starcke & Brand, 2012). Moreover, it may advocate that acute stress does not necessarily impede decision making (Starcke & Brand, 2012). It might therefore support that individuals will react differently depending on whether the stressor is perceived as merely a challenge or a threat (Starcke & Brand, 2012).

1.4.4 Limitations of Previous Research

The application and timing of the laboratory induced stressors often differed, as well as the type and intensity of the stress (Starcke & Brand, 2012). Furthermore, previous research frequently had comparatively small sample sizes of the stress reactive groups (Berghorst et al.,

2013). While physiological and self-report measures were utilised to disassociate stress responders from non-responders, the methods across studies were not consistent (Starcke & Brand, 2012; Simonovic et al., 2016). Additionally, the laboratory induced stressors lacked ecological validity, and therefore have reduced generalisability to real life settings (Berghorst et al., 2013). Moreover, Berghorst et al.'s (2013) study had only female participants, which is a clear limitation, as research has shown that females demonstrate more prominent reactivity to stress (Berghorst et al., 2013). It must also be noted that the moderate stressor and task demands in Van Gemmert and Van Galen's (1997) study were insufficient to provide a large effect on reaction time.

1.5 The Relationship Between Acute Stress and Learning

The current study is moreover focused on the effects of acute stress on learning. Early research has demonstrated that the effects of acute stress on learning are relative to the intensity of the stressor, in addition to the difficulty of the learning task (Teigen, 1994). This relationship has been described as the Yerkes Dodson Law (Salehi et al., 2010; Teigen, 1994). The Yerkes Dodson Law is a theory that has been utilised to describe the interaction between various concepts, such as anxiety and stress in relation to learning (Teigen, 1994). The relationship between these concepts is characterised by an inverted 'U' as variables have a curvilinear relationship (Cavanagh et al., 2010; Preston et al., 2007; Salehi et al., 2010; Teigen, 1994). In its infancy the Yerkes Dodson Law was applied to discrimination learning, the ability to differentiate between stimuli that lead to different outcomes (Teigen, 1994). Discrimination learning has been found to occur more slowly in animals when the acute stressors are either too weak or too strong (Teigen, 1994). However, this finding was found to be relative to the difficulty of the task (Teigen, 1994). Further studies conducted on animals and humans have

consistently reported a similar inverted 'U' relationship between the effects of acute stress on learning (see Figure 3; Cavanagh et al., 2010; Preston et al., 2007; Salehi et al., 2010; Teigen, 1994).

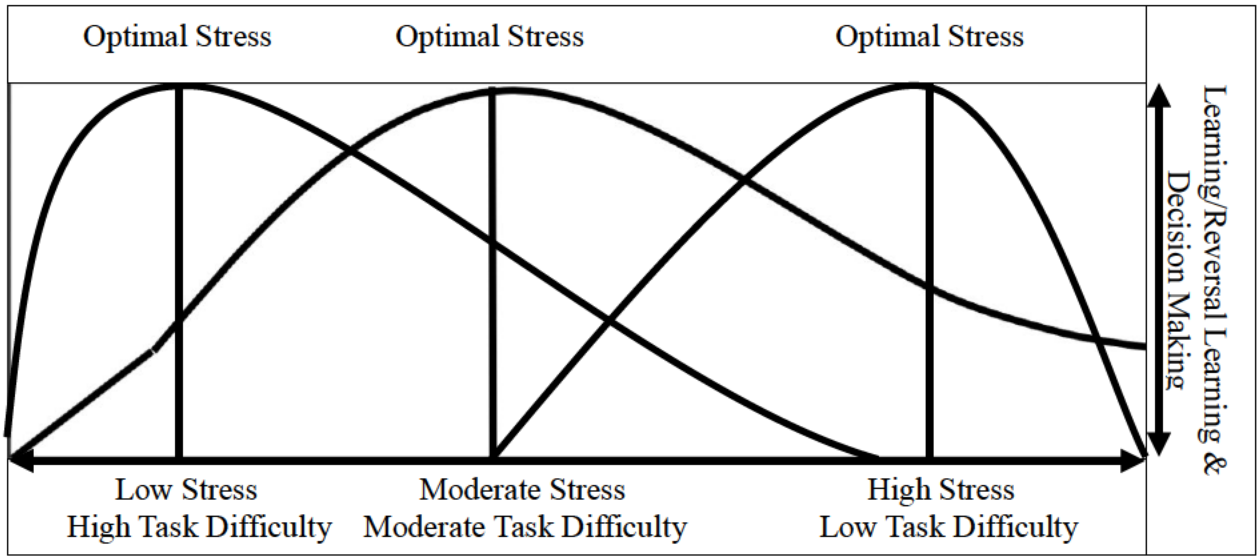

Figure 3. The conceptualisation of the Yerkes Dodson Law in the present thesis. Figure adapted from Teigen (1994).

In recent research it has been found that acute stress enhances aversive conditioning – learning that a stimulus has aversive consequences – in both animals and humans (Robinson et al., 2013). It has also been found that acute stress can reduce reward responsivity (Bogdan & Pizzagalli, 2006). Yet certain acute stressors have induced improvements in appetitive learning (Berghorst et al., 2013; Robinson et al., 2013). In addition, acute stress has been found to potentially hinder, aversive learning, reinforcement learning and reversal learning in threat conditions (LeBlanc, 2009; Raio et al., 2017; Shafiei et al., 2012). The results of these previous studies are therefore inconsistent. It is possible that individual differences in the participants' response to acute stress may account for the various findings that stress impairs or improves learning (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Cavanagh et al., 2010; Preston et

al., 2007; Salehi et al., 2010; Starcke & Brand, 2012). Moreover, these differences may result in acute stress being perceived as either a challenge or a threat, thereby causing neurophysiological changes to be either beneficial or detrimental to learning (Berghorst et al., 2013; Cavanagh et al., 2010; LeBlanc, 2009; Starcke & Brand, 2012). Research advocates that these neurophysiological changes impact the neural pathways in the striatum of the BG, amygdala, and the ventromedial-orbitofrontal cortices (Doll & Frank, 2009; Frank & Claus, 2006; Lighthall et al., 2011; Lighthall et al., 2013; Raio et al., 2017; Schroll & Hamker, 2013; Starcke & Brand, 2012). It is therefore possible that learning, as with decision making, can be improved or impaired based on whether acute stress is perceived as merely a challenge or as a threat (see Table 1; Cavanagh et al., 2010; Starcke & Brand, 2012).

Table 1

Overview of the Concepts Utilised in this Dissertation Relative to the Yerkes-Dodson Law.

Independent Variables		Dependent Variables
Acute Stress	High Conflict Decision	Accuracy During Learning
State Anxiety	Low Conflict Decision	Accuracy During Reversal Learning
		Reaction Time During Decision Making

Note. The Concepts in the First Column should Theoretically Interact with the Concepts in the Second Column, Before Affecting the Concepts in the Third Column**.** Table adapted from Teigen **(**1994).

1.5.1 Previous Studies Investigating the Relationship Between Acute Stress and Learning

The initial experiments that lead to the development of the Yerkes Dodson Law in 1908 involved three sets of discrimination learning experiments on mice (Salehi et al., 2010; Teigen,

1994). In the first set of experiments it was found that weak electric shocks resulted in slower rates of learning (Teigen, 1994). When the intensity of the aversive stimuli was increased in the second set of experiments the rate of learning was improved, yet at the strongest level of intensity the rate of learning was once again decreased (Teigen, 1994). The result was the discovery of the fabled inverted U-curve relationship between acute stress and learning (Teigen, 1994). Further experimentation with easier or more difficult discrimination tasks evidenced that the optimal stimulus strength for learning (habit formation), was relative to the task difficulty (Salehi et al., 2010; Teigen, 1994).

Similar experiments have been conducted on chickens, kittens, rats and human subjects with comparable results that reveal an inverted 'U' relationship (Preston et al., 2007; Salehi et al., 2010; Teigen, 1994). In Broadhurst's more precise experiments, rats were subjected to differing lengths of air deprivation before the beginning of each trial to induce different levels of stress (Salehi et al., 2010). The result was consistent with previous experiments, in that acute stress was either beneficial or detrimental to learning, relative to the task difficulty (Salehi et al., 2010). The additional benefit of Broadhurst's experiments was the provision of a stronger empirical and theoretical foundation for the Yerkes Dodson law (Teigen, 1994).

Successive research prior to and following Broadhurst's contribution have investigated the effects of acute stress on reward and punishment learning (Bogdan & Pizzagalli, 2006; Cavanagh et al., 2010; Preston et al., 2007; Teigen, 1994). Such research has consistently reported results supportive of the Yerkes Dodson inverted-U relationship between acute stress and learning (Cavanagh et al., 2010; Preston et al., 2007; Salehi et al., 2010; Teigen, 1994). In Bogdan & Pizzagalli's (2006) study exploring the effects of acute stress on reward responsiveness, it was found that participants exhibited significantly reduced responsivity to

reward learning in the threat condition. In other words, participants were considerably less able to modulate their decisions as a function of previous rewards (Bogdan & Pizzagalli, 2006). This finding was partially supported in a similar experiment using speech anticipation to induce acute stress (Preston et al., 2007). Preston et al.'s (2007) study observed that stress hindered the participants' learning in the Iowa Gambling Task (IGT), in which the required response to obtain positive feedback is switched several times without informing participants. This resulted in participants in the threat condition taking longer to shift toward the new advantageous option (Preston et al., 2007).

Several studies have also investigated the relationship between individuals' stress reactivity and learning (Cavanagh et al., 2010; Otto et al., 2013; Salehi et al., 2010). Salehi et al. (2010) observed an inverted U relationship with acute stress and learning in rats relative to personality profiles (Behavioural Traits). This finding was also supported in Cavanagh et al.'s (2010) study using a probabilistic stimulus selection task (PSST). Cavanagh et al. (2010) observed the effects of social stress reactivity on punishment and reward learning, where individuals with greater trait vulnerability (punishment sensitivity) had higher punishment learning, while the reverse was found in participants with lower trait vulnerability (Cavanagh et al., 2010). These findings were furthermore supported in a similar study conducted on female participants utilising a PSST (Berghorst et al., 2013). In Berghorst et al.'s (2013) experiment, participants classified as stress responders displayed significant reductions in reward learning in the stress condition. Moreover, as in Cavanagh et al.'s (2010) study, stress responders did not display the same deficits to punishment learning.

Contrary to these findings, however, Lighthall et al. (2013) found that acute stress induced via cold pressor, a procedure in which the participant is asked to immerse their hand in

ice water, significantly enhanced reward learning from positive outcomes during a PSST. Additionally, participants also demonstrated reduced aversive learning from negative outcomes (Lighthall et al., 2013). Nevertheless, as in Preston et al.'s (2007) experiment, the acute stress was found to impair reinforcement learning in the initial phases, regardless of positive or negative feedback (Lighthall et al., 2013). Conversely, in recent research conducted by Raio et al. (2017), in spite of acute stress, initial learning was unaffected, but reversal learning was impaired. In Raio et al.'s (2017) experiment, participants initially completed an aversive learning task prior to a reversal learning phase. The participants learned to associate one stimulus with safety, while another was probabilistically associated with an electric shock. Prior to the reversal learning phase, experimental participants endured an acute stress manipulation. It was found that experimental participants had significant impairments in aversive reversal learning (Raio et al., 2017).

Though there are clear discrepancies within this finite body of research, it is evident that acute stress affects learning. The extent of these effects remains unclear and is theoretically relative to the intensity of the acute stress, the difficulty of the learning task (Teigen, 1994). Furthermore, individual stress reactivity might determine if acute stress benefits or impairs learning (Cavanagh et al., 2010; Otto et al., 2013; Raio et al., 2017; Salehi et al., 2010).

1.5.2 Limitations of Previous Research

Though the Yerkes Dodson Law has withstood the test of time since its inception in 1908, there has been a lack of consensus as to its actual implications amongst psychologists (Teigen, 1994). Furthermore, Broadhurst's experiments induced acute stress levels that were extrinsic to the discrimination task, as opposed to being intrinsic to cognitive demands (Salehi et al., 2010). It is also worth noting that the majority of early experiments were conducted on animals and

often had relatively small sample sizes, thus reducing their generalisability to human populations (Preston et al., 2007; Salehi et al., 2010; Teigen, 1994). Moreover, several studies focused on individual differences impacting punishment or reward learning, yet there is no consensus as to which individual differences cause stress reactivity (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006). In addition, as with Berghorst et al.'s (2013) research, the study by Bogdan and Pizzagalli (2006) only tested female participants, whom tend to have greater stress reactivity. Furthermore, Lighthall et al.'s (2013) extraneous memory task and PSST were administered well after the acute stress was induced. The potential relief from the stressor could theoretically increase DA levels and activate reward related neural areas in the brain, thereby inadvertently impacted their results (Lighthall et al., 2013).

1.6 State Anxiety as a Predictor of Stress Reactivity

State anxiety is the transitory affective state that typically occurs in response to stressful conditions (Spielberger, 1983; Spielberger et al., 1983). These temporary affective states are characterised by subjective feelings of apprehension, nervousness, tension and worry (Spielberger et al., 1983). The intensity of state anxiety can vary and fluctuate over time (Spielberger et al., 1983). This intensity might be relative to an individual's perception of conditions as threatening (Spielberger, 1983; Spielberger et al., 1983). Additionally, state anxiety also involves the activation or arousal of the autonomic nervous system (Spielberger, 1983; Spielberger et al., 1983). Several studies have assessed changes in state anxiety in order to assess subjective stress reactivity (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Lukasik et al., 2019; Preston et al., 2007; Starcke & Brand, 2012). Furthermore, research has demonstrated that there is significant neurophysiological comorbidity between state anxiety and stress (Lukasik et al., 2019). Since state anxiety correlates with neurophysiological changes in response to acute

stress, it is therefore an apt predictor of stress reactivity (Berghorst et al., 2013; Lukasik et al., 2019; Preston et al., 2007; Spielberger et al., 1983; Starcke & Brand, 2012).

1.7 The State Anxiety Inventory as a Measure of Stress Reactivity

The state subscale of the State Trait Anxiety Inventory (STAI-S; Spielberger et al., 1983) is an appropriate measure for the current study, as it can assess situational stress induced affective changes (Spielberger et al., 1983). These situational affective changes occur in response to conditions perceived as psychologically threatening (Spielberger et al., 1983). The STAI-S has been utilised in numerous experiments to measure subjective stress reactivity in research and to disassociate stress responders from non-responders in several experiments (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Lukasik et al., 2019; Preston et al., 2007; Starcke & Brand, 2012).

1.8 The Current Study

The primary determination of the current study is to methodically discern the effects of acute stress on learning, reversal learning and decision making. This will be achieved via the use of a threat inducing stress test with a PSST. Furthermore, the STAI-S will be utilised to disassociate stress responders from non-responders. The STAI-S is an established predictor of stress reactivity and is therefore crucial as a criterion variable. Moreover, this study intends to discern if the effects are influenced by participants' individual differences in response to the threat manipulation (their stress reactivity). The specific aims and hypothesis are displayed in Table 2. To our knowledge, no other study has investigated the effect of stress on all three measures (learning, reversal learning and decision-making) while also taking into account individual differences in stress reactivity.

Table 2

Aims and Hypothesis for the Current Study

Aim 1 To determine the effect of a threat manipulation on learning and reversal learning. **Hypothesis 1:** It is expected that the mild acute stress induced by our threat manipulation should improve learning and reversal learning.
Aim 2 To examine the effect of a threat manipulation on decision-making. **Hypothesis 2:** It is expected that the acute stress induced by the threat manipulation should increase decision making reaction times.
Aim 3 To explore whether these effects are influenced by individual differences in the way people respond to the threat manipulation (i.e., divide people into stress responders and non-responders as in previous studies). Furthermore, to investigate whether this influences how the threat manipulation affects learning, reversal learning and decision-making). **Hypothesis 3:** It is expected that participants classed as stress responders will have significantly increased reaction times in contrast to non-responders in response to acute stress induced by the threat manipulation. **Hypothesis 4:** It is expected that participants classed as stress responders will have significantly improved learning and reversal learning in response to acute stress induced by the threat manipulation.

2 Method

2.1 Participants

Forty individuals were recruited via personal contacts to participate in the study (21 males and 19 females, mean age = 27.6). All participants gave informed consent after being given the information sheet (see Appendix B) It was assumed that all students would meet the minimum language requirements to participate, as students enrolled in tertiary education in Australia should be proficient in English.

2.2 Materials

A threat inducing stress test with a Probabilistic Stimulus Selection Task (PSST) was created for data collection (see Figure 4-13). Furthermore, the State Scale (STAI Form Y-1) of the State Trait Anxiety Inventory (STAI) was used to evaluate present state anxiety levels (see Appendix A). The State Scale of the STAI is a 20-item questionnaire with a 4-point Likert scale. In addition, the STAI-S has established high reliability and validity (Spielberger et al., 1983). Given the transitory nature of state anxiety, the STAI-S high internal consistency (Cronbach's alpha = 0.90) is important (Spielberger et al., 1983).

2.2.1 Participant Stress

As in previous research, participants were divided into stress responders and non-responders to discern if stress reactivity had an effect on learning, reversal learning and decision making (Berghorst et al., 2013; Lukasik et al., 2019; Preston et al., 2007; Starcke & Brand, 2012). Participants were classed as stress responders if they expressed significant increases in present state anxiety, in response to the threat condition relative to the safe condition (see Figures 15 and 16). Present state anxiety levels were assessed before and after the learning phases of the safe and threat conditions.

2.3 Procedure

Participants completed the State Anxiety Inventory (STAI-S) before and after learning in two conditions, a safe and a threat condition. During the learning task, participants learned to associate symbols with correct or incorrect feedback (see Figure 8 and 12). They completed both safe and threat conditions, but they learned about different sets of symbols in each condition. Each condition consisted of an acquisition training phase, a high/low conflict decision-making test, and a reversal learning test. The acquisition and reversal phases were training phases, so participants received feedback after every symbol selection, whereas the high/low conflict test phase did not include any feedback (participants were required to select a symbol on every trial, but the feedback was omitted).

On each training trial participants were shown two symbols side by side and were required to select one of them by pressing a key on the corresponding side (left or right) of the keyboard (see Figures 4, 7 and 11).

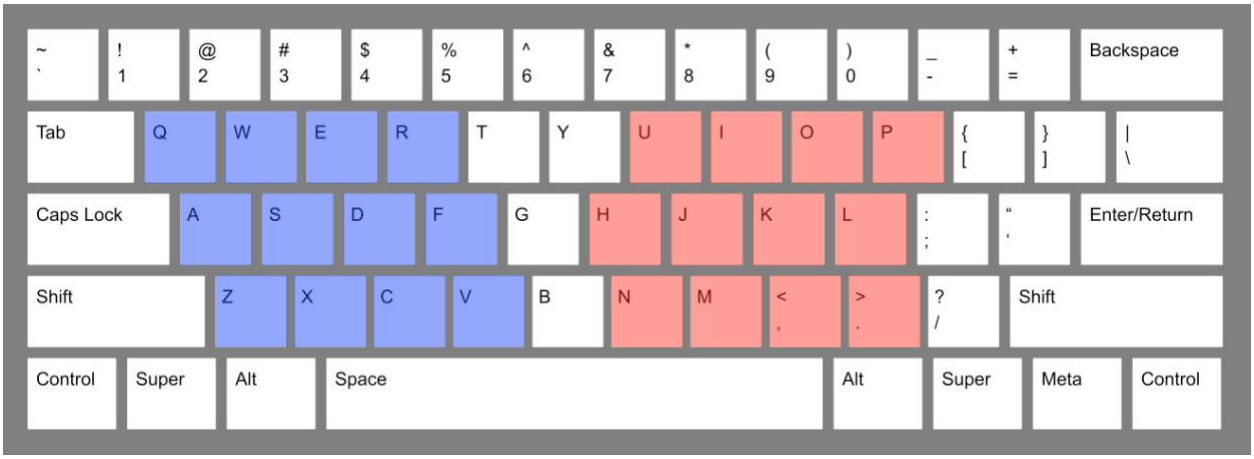

Figure 4. Illustration of the keyboard keys that could be used to make a selection in the experiment (the blue keys could be used to select the stimulus on the left of the screen, and the red to select the stimulus on the right).

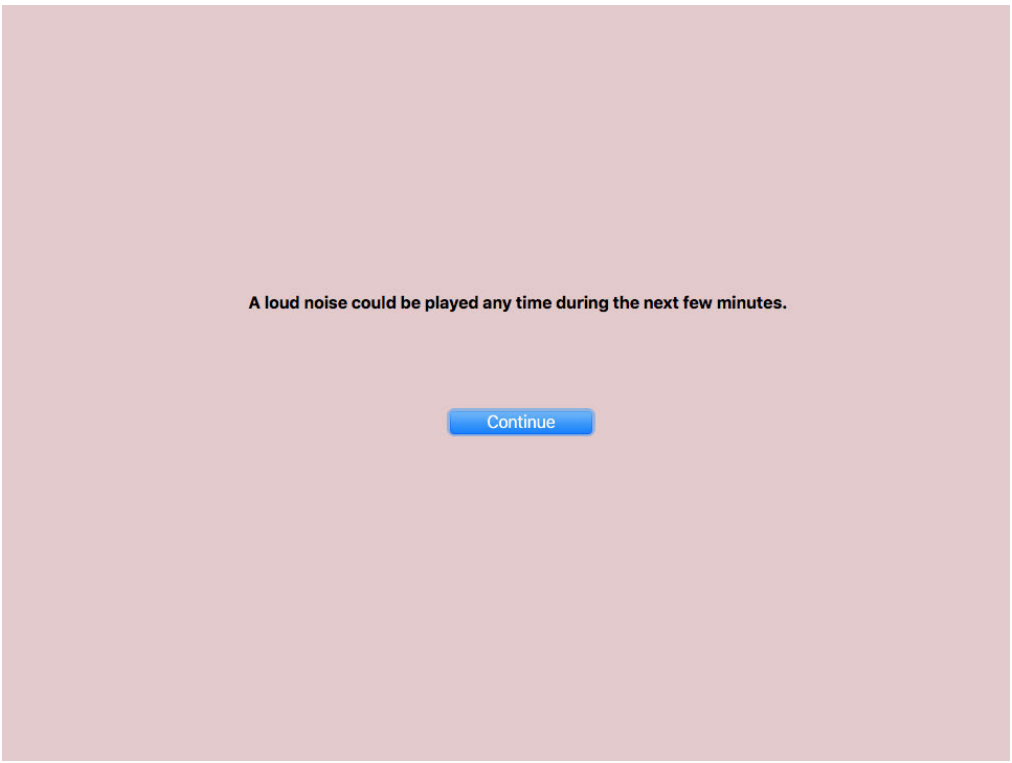

Figure 5. Pink screen from the threat acquisition phase stating that a loud noise could be played.

Figure 6. Training trial illustrating two symbols side by side.

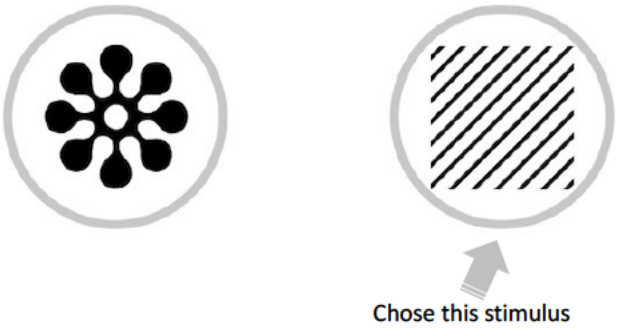

Figure 7. Training trial illustrating the selection of two symbols side by side.

Figure 8. Training trial feedback screen displaying the selection as incorrect.

Figure 9. Pink screen from the threat acquisition phase.

Figure 10. Second training trial illustrating two symbols side by side.

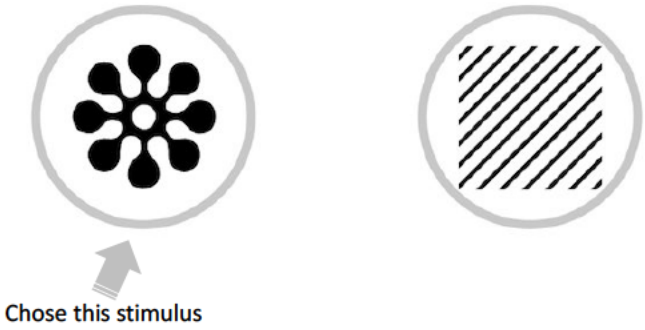

Figure 11. Training trial illustrating the selection of two symbols side by side.

Figure 12. Training trial feedback screen displaying the answer as correct.

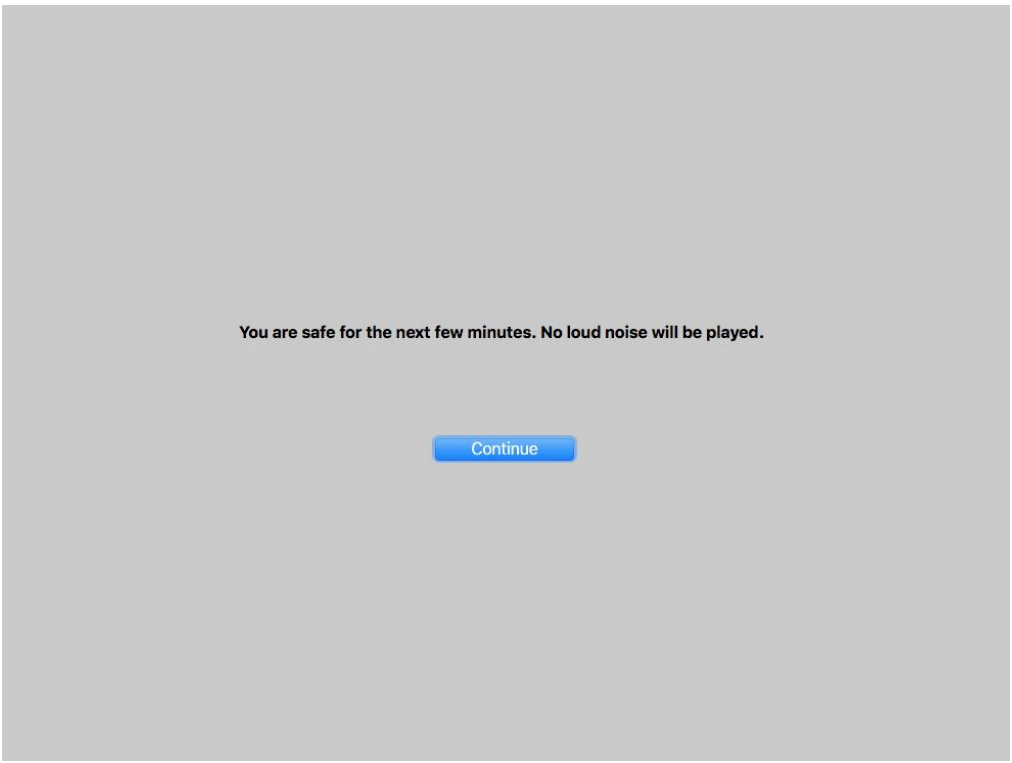

Figure 13. Grey screen from the safe acquisition phase stating that a loud noise would not be played.

Subjects were then shown a feedback screen that displayed either the word 'Correct!' or 'Incorrect' (as in Figures 8 and 12). Participants needed to learn through trial and error which symbol to choose from each pair. Subjects had 4s to make their selection, and if they did not make a response within this period, the feedback screen displayed the words 'no response detected'. The feedback screen was shown for 1s, with trials separated by an inter-trial period of 1.5s. Test trials were identical to the training trials, except that new combinations of symbols were presented in order to test their ability to apply what they had learnt to make new decisions, and no feedback was given after participants selected a symbol.

The threat manipulation was only applied to the acquisition phase of the threat condition. In the threat acquisition phase, the inter-trial interval consisted of a pink screen (Figure 9) and subjects were informed that they could hear a loud noise of maximum 85-dB any time a pink

screen was shown (Figure 5). Each of five different sounds - Alien Death Scream, Infant Crying, Predator Roar, Tyrannosaurus Rex Roar and Woman Screaming - were played once after trials 3, 20, 50, 70, and 100, respectively (see Appendices A and D; Figure 14).

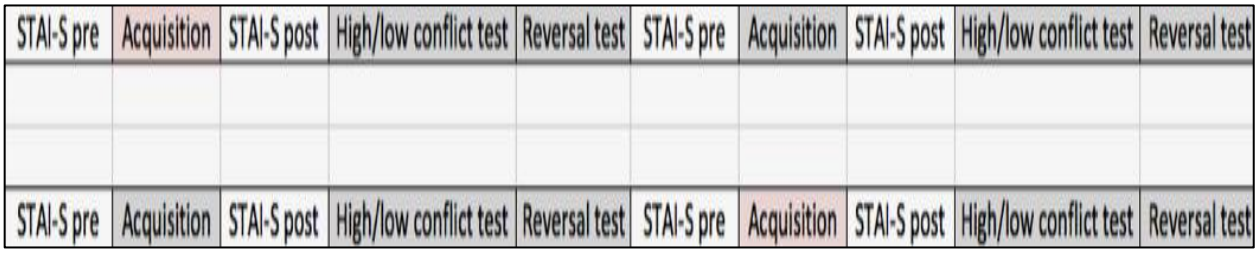

Figure 14. Illustration of the sequence of the probabilistic stimulus selection task (PSST) training and test phases. The pink box signifies the threat condition. Half of the participants completed the threat condition first and the other half completed the safe condition first.

Participants were 'safe' from any sound in all other phases of the learning task. This was indicated a grey screen during the inter-trial interval. Participants were therefore tested in the same safe condition, so any differences in performance on the test or during the reversal phase could be attributed to differences in acquisition, which either happened in safe conditions or under threat (see Figure 13).

In the acquisition phase, participants saw four pairs of symbols (each symbol was denoted by a different letter). The likelihood of receiving positive feedback after selecting each symbol is indicated in parentheses in Table 3. In the test phase, participants were shown novel combinations of the symbols. In high conflict test trials, two symbols with similar reinforcement histories were paired (e.g., A and E, which had been associated with 90% and 75% positive feedback, respectively). While, in low conflict test trials, two symbols with very different histories were paired (e.g., A and F, which had been associated with 90% and 25% positive feedback, respectively). Therefore, decisions should be made more easily, and potentially faster, on low conflict trials than on high conflict trials. In the reversal test, the reinforcement

contingencies were reversed for two of the symbol pairs, AB and EF. The same design was repeated in the two conditions, yet different symbols were used. These were assigned randomly to each reinforcement contingency for each participant (see Figure 6 and 10; Table 3).

Table 3.

Overview of the Percentage of Positive Feedback Probabilities

Acquisition	High/Low Conflict Test		Reversal Test
	High Conflict Trials	Low Conflict Trials	
A(90%) B(10%)	AE	AF	A(10%) B(90%)
C(90%) D(10%)	AG	AH	C(90%) D(10%)
E(75%) F(25%)	CE	CF	E(25%) F(75%)
G(75%) H(25%)	CG	CH	G(75%) H(25%)
	BF	BE	
	BH	BG	
	DF	DE	
	DH	DG	
		CB	
		AD	
		EH	
		GF	

Note. The pairs of stimuli have similar reinforcement histories in high conflict trials. While on low conflict trials, the pairs of stimuli are associated with very different reinforcement histories.

Performance on AB trials was analysed (given that this contingency was reversed in Phase 2 and was the easiest to learn). The learning measure was the proportion of A choices in Phase 1 (with a higher proportion reflecting better learning performance), and the reversal learning measure was the proportion of A choices in Phase 2 (with a lower proportion reflecting better reversal learning).

Reaction times were analysed in the test phase. By way of previous studies, we compared reaction times on high-conflict trials to those on low conflict trials (Frank et al., 2007; Schroll & Hamker, 2013). On high conflict trials, the decision should be more difficult since stimuli with similar reinforcement histories are paired (e.g., A and E, where they were each reinforced 90% and 75% respectively). In contrast, on low conflict trials the decision should be far less difficult as stimuli are associated with very different histories (e.g., A and F, which had been associated with 90% and 25% positive feedback, respectively). Therefore, individuals usually respond more slowly on high conflict trials, this is a measure of the ability to withhold making a decision until enough information is gathered.

The learning tasks included two parts that tested learning and decision-making in stressful versus safe conditions. Participants were randomly assigned to either a safe-first or a threat-first condition, and they were required complete both conditions in a repeated measures design (Figure 14).

3 Results

3.1 Description of Participants

Participants were divided according to their change in STAI-S scores after each condition. That is, they were classified as responders if their change was more positive after the threat condition than after the safe condition (see Figures 15 and 16). For the $N = 40$ participants

there were 20 stress responders and 20 non-responders. The mean age for responders was 27.0 years (*SD* = 2.01), and fifty percent were female (*n* = 10). The mean age for non-responders was 28.2 years (*SD* = 2.84), and forty-five percent were female (*n* = 9; see Table 4).

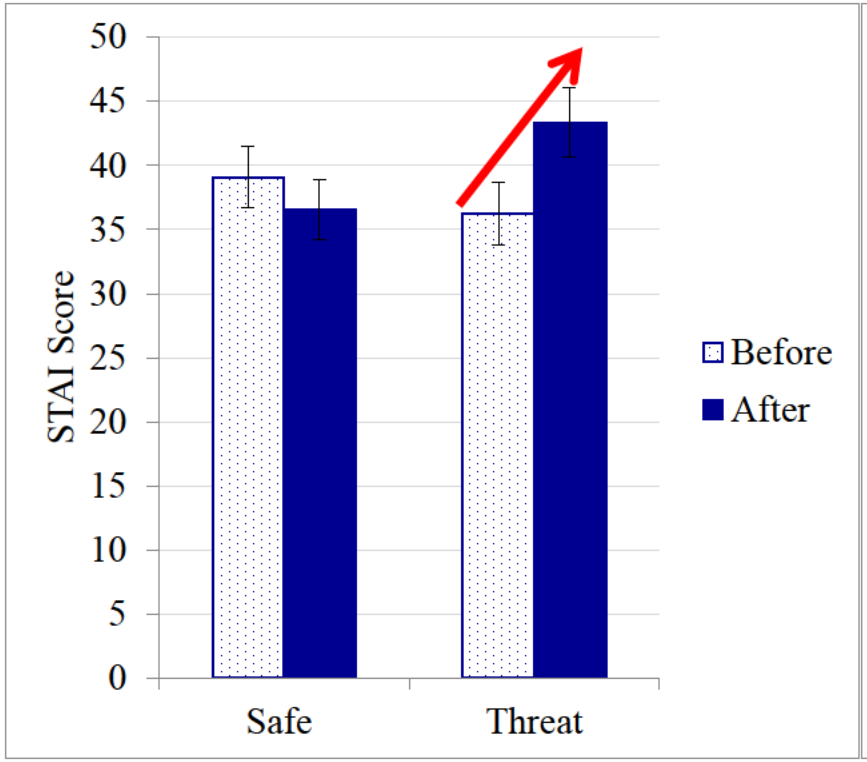

Figure 15. Responders' STAI-S scores in each condition.

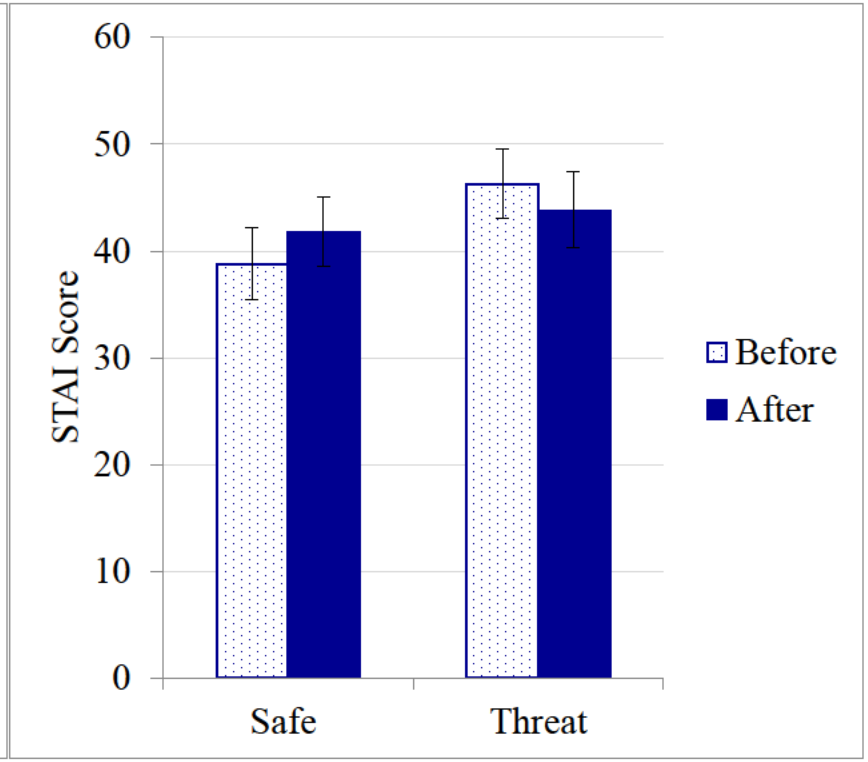

Figure 16. Non-responders' STAI-S scores in each condition.

Table 4

Demographics for Responders and Non-Responders

Variable	Responders	Non-Responders
Age	27.0	28.2
% Females	50	45
% Males	50	55
STAI-S Difference Score	**7.1**	**-5.5**

Note. The 20 responders and non-responders are similar in age and gender. Bolded values indicate statistical significance. STAI-S Difference Score = (Score post threat – Score pre threat) – (Score post safe – Score pre safe).

3.2 Aim 1: The Effect of Acute Stress on Learning and Reversal learning

Participants learning and reversal learning performance measures were analysed via a mixed ANOVA with two repeated factors (Training phase and Threat condition) and one between-subjects factor (Responder vs Non-responder). We performed a 2 (Phase 1 vs Phase 2) x 2 (Threat condition vs Safe condition) x 2 (Responder vs Non-responder) ANOVA. There was a main effect of phase, as the proportion of A choices was much higher in Phase 1 than in the reversal Phase 2, $F(1, 38) = 49.48$, $p < .001$, $\eta_p^2 = .566$. There was also a threat condition by phase interaction, $F(1, 38) = 4.89$, $p = .033$, $\eta_p^2 = .114$. This occurred because although Phase 1 learning was similar in the two conditions ($t(39) = .69$, $p = .496$), there was better reversal learning in the threat condition in Phase 2 ($t(39) = 2.33$, $p = .025$). No other effects were significant (see Figures 17 and 18).

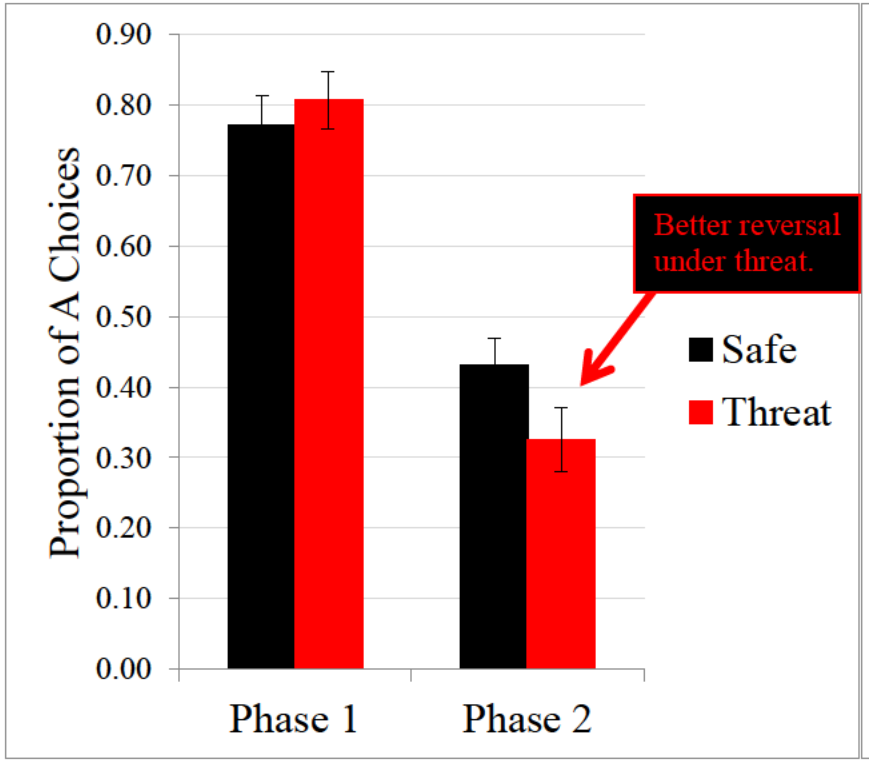

Figure 17. Proportion of A choices made by responders.

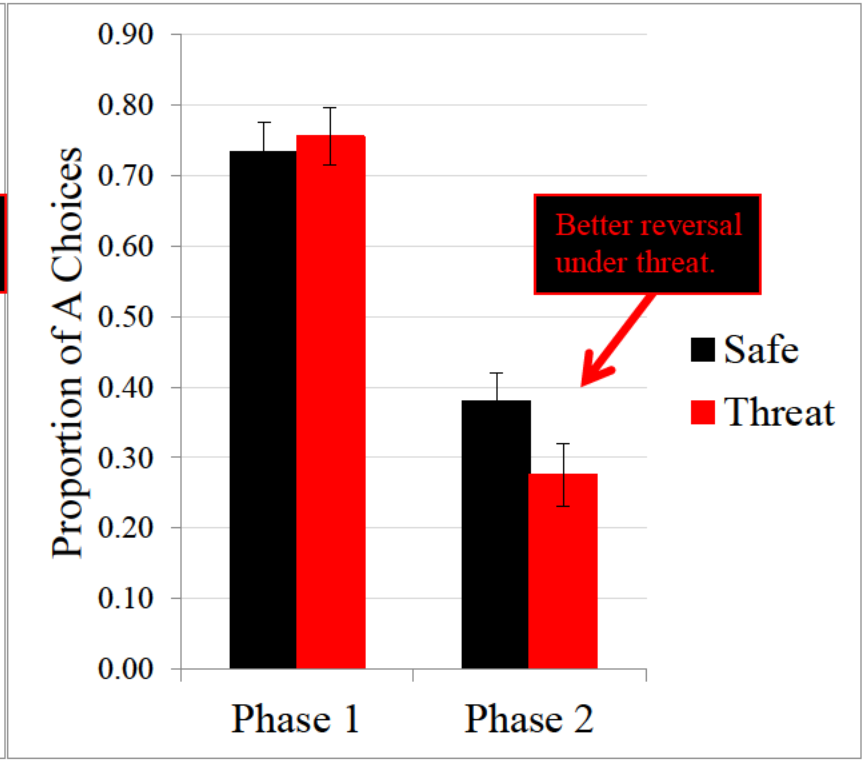

Figure 18. Proportion of A choices made by non-responders.

3.3 Aim 2: The Effect of Acute Stress on Decision-Making in High vs Low Conflict Trials

Participant reaction times were analysed on test trials via a 2 (High vs Low conflict trial) x 2 (Threat condition vs Safe condition) x 2 (Responder vs Non-responder) ANOVA. There was a main effect of type of trial, as there were slower reaction times on high conflict trials relative to low conflict trials [$F(1, 38) = 7.84$, $p = .008$, $\eta_p^2 = .171$], replicating previous studies (Frank et al., 2007; Schroll & Hamker, 2013). There was an interaction between type of trial and responder group, $F(1, 38) = 5.39$, $p = .026$, $\eta_p^2 = .124$. In addition, as in other studies, there was an interaction between the threat condition and responder group, $F(1, 38) = 4.11$, $p = .050$, $\eta_p^2 = .098$ (Berghorst et al., 2013; Lighthall et al., 2011; Mather & Lighthall, 2012; Shafiei et al., 2012; Starcke & Brand, 2012). Because of these two interactions, we performed separate ANOVAs on each responder group. In the responder group there was a main effect of type of trial, as responders had the typical slower reaction times on high conflict trials, $F(1, 19) = 12.70$, $p = .002$, $\eta_p^2 = .401$. In contrast, in the non-responder group there was only a main effect of threat condition, as their reaction times were faster in the threat condition than in the safe condition, $F(1, 19) = 4.73$, $p = .042$, $\eta_p^2 = .19$, but they did not slow down on high conflict trials (Figures 19 and 20).

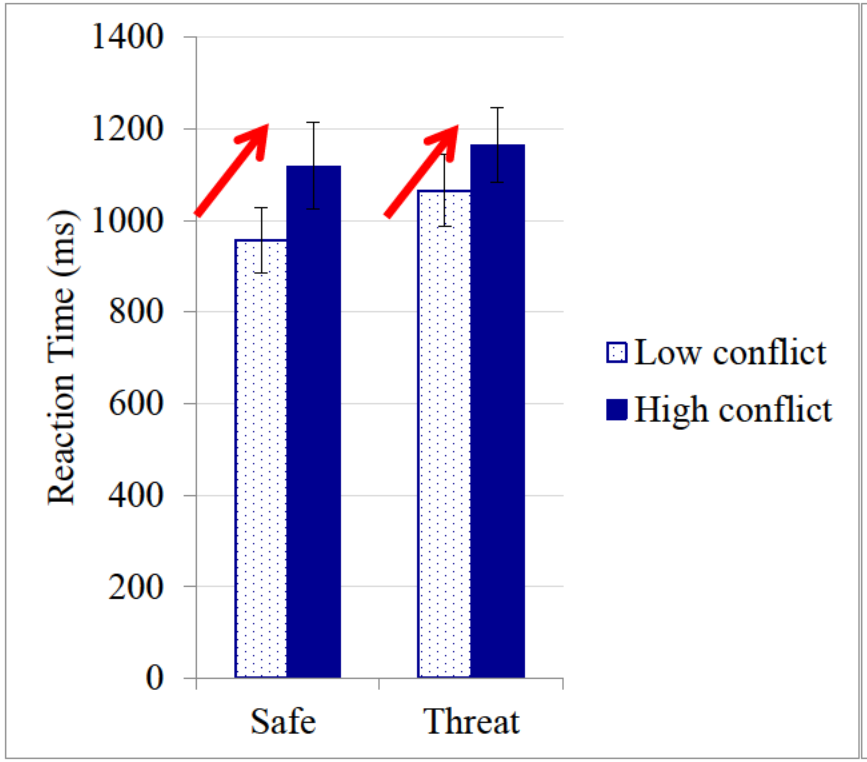

Figure 19. Responders' reaction times at test.

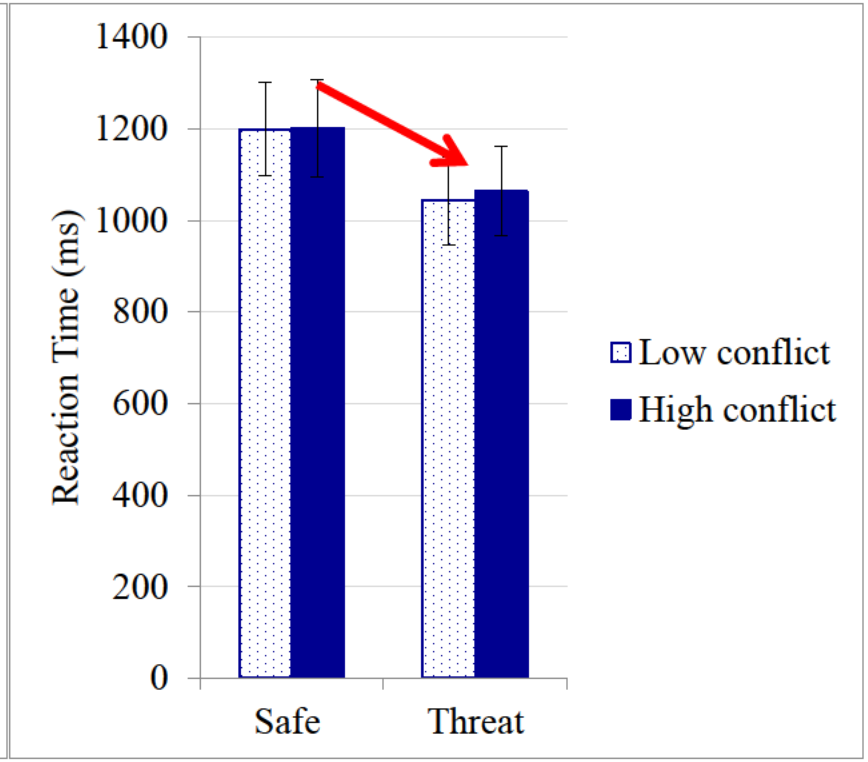

Figure 20. Non-responders' reaction times at test.

4 Discussion

4.1 Aim 1: The Effect of Acute Stress on Learning and Reversal learning

The first aim of the study was to determine the effect of acute stress on learning and reversal learning. It was found that reversal learning significantly improved in the threat condition, but not initial phase 1 learning. Additionally, this effect was found to be similar for responders and non-responders as during reversal learning in the threat condition, both groups demonstrated a marked improvement. These findings were partially supportive of hypothesis 1. A possible explanation for the absence of a significant improvement in the initial phase 1 learning task, is suggested in the Yerkes Dodson law (Teigen, 1994). It might be that the initial phase 1 learning task may have been too easy, relative to the mild acute stress in the threat condition. Therefore, there was no marked improvement in learning. Inversely, the phase 2 reversal learning task, being more of a challenge, might have the additional benefit of being an intrinsic stressor. Previous research supports that intrinsic stress (stimulated by components related to the cognitive task) can be beneficial to learning (Preston et al., 2007; Salehi et al., 2010). This coupled with the threat condition could have made the reversal phase more inducive to learning, as the stress level was optimal, relative to the task difficulty (Figure 3; Table 1).

4.2 Aim 2: The Effect of Acute Stress on Decision-Making in High vs Low Conflict Trials

The second aim of the study was to assess the effects of acute stress on decision making in high vs low conflict trials. Though at the group level it was found that there was no effect of the threat manipulation on decision making reaction times at test, hypothesis 2 was partially supported, as both high vs low conflict and the threat manipulation interacted with responder group. Furthermore, as expected responders had significantly increased reaction times (Slowed Down). This significant increase in reaction times was in response to the stress manipulation

(threat phase) and increased even more so during high conflict decision making. Non-responders, however, were shown to significantly decrease their reaction times (speed up) (see Figure 19 and 20).

The current study is aligned with the findings of similar research observing that stress responders have significant increases in reaction times in response to acute stress (Berghorst et al., 2013; Shafiei et al., 2012; Starcke & Brand, 2012). One might postulate that the acute stress incurred by the threat condition resulted in a sudden increase in Dopamine (DA) affecting the indirect and hyperdirect pathway of the basal ganglia (BG) in the striatum. This could potentially have resulted in responders slowing down in response to the threat phase and high conflict decisions. Inversely, it is possible that non-responders did not have that boost in DA and therefore their decision making was not improved (see Figure 21).

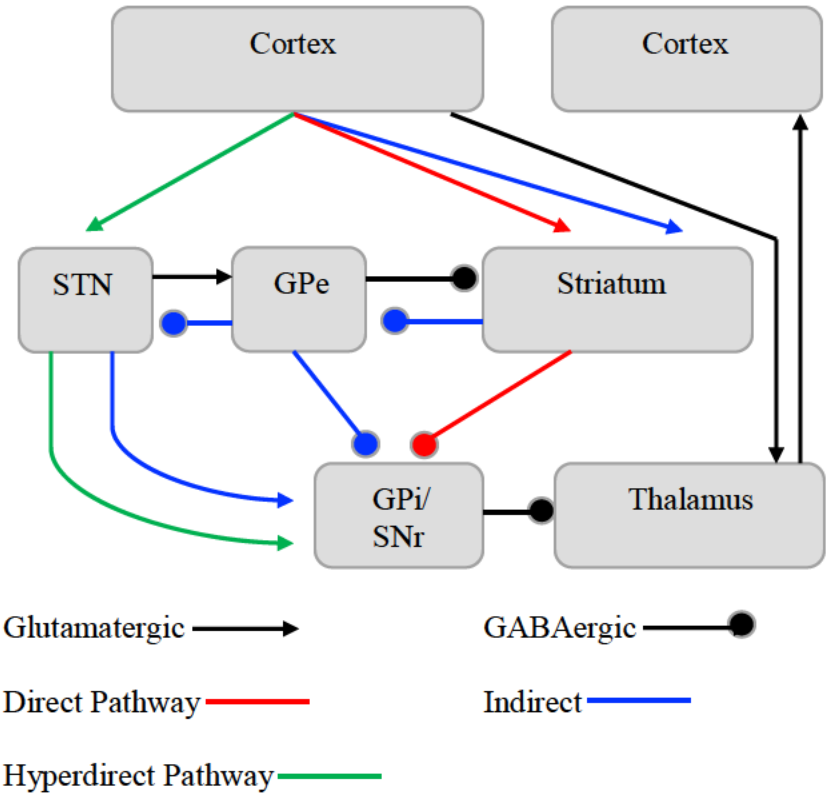

Figure 21. Illustration of the cortico-BG-thalamic fiber tracts and their subdivision into direct, indirect and Hyperdirect BG pathways. Two paths have been proposed for the indirect pathway. Figure adapted from Schroll & Hamker (2013).

4.2.1 Considering State Anxiety as a Predictor of Stress Reactivity

The current study also utilised state anxiety as a predictor of stress reactivity. State anxiety has been measured extensively in a wide variety of demographics to assess stress reactivity in response to experiments and real-life stressful events (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Lukasik et al., 2019; Preston et al., 2007; Spielberger et al., 1983; Starcke & Brand, 2012). State anxiety is essential in that it can assess stress reactivity without the presence of the neuroendocrine cascade (Lukasik et al., 2019). Therefore, with the current experiment being behavioural in nature, state anxiety was the most pertinent predictor of stress reactivity. The present study has successfully replicated the findings of previous research by

assessing the increases in present state anxiety in response to the threat condition, contrasted to the safe condition (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Goette, Bendahan, Thoresen, Hollis, & Sandi, 2015; Salehi et al., 2010; Starcke & Brand, 2012). Furthermore, the current experiment has been effective in utilising state anxiety to disassociate responders from non-responders. Therefore, state anxiety is an apt predictor of stress reactivity.

4.3 Aim 3: To Determine if Stress Reactivity Impacts Learning, Reversal learning or Decision Making.

The third aim of the study was to explore whether individual differences influence the way people respond to the threat manipulation (i.e., divide people into stress responders and non-responders as in previous studies) (Berghorst et al., 2013; Lukasik et al., 2019; Preston et al., 2007; Starcke & Brand, 2012). Furthermore, the present study intended to investigate whether individual differences influence how the threat manipulation affects learning, reversal learning and decision-making). Hypothesis 3 was supported as responders significantly slowed down their reaction times in response to threat, which has been found in previous studies (Berghorst et al., 2013; Lighthall et al., 2011; Mather & Lighthall, 2012; Shafiei et al., 2012; Starcke & Brand, 2012; Steinhauser et al., 2007; Van Gemmert & Van Galen, 1997). Moreover, responders increased reaction times in high conflict trials as found in previous research (Frank et al., 2007; Schroll & Hamker, 2013). In contrast, non-responders significantly sped up their reaction times under threat. However, hypothesis 4 was not supported as stress reactivity had no effect on learning or reversal learning in response to the threat manipulation.

There is evidence that acute stress is correlated with a neuroendocrine cascade that initiates the sympatho-adreno-medullary axis of the autonomic nervous system (Otto et al., 2013; Raio et al., 2017). This in turn triggers the release of catecholamines (e.g., DA,

noradrenaline/norepinephrine), thereby actuating the hypothalamic-pituitary-adrenal axis (HPA) (Otto et al., 2013; Raio et al., 2017). This results in the release of glucocorticoids (e.g., cortisol in humans, corticosterone in animals) (Raio et al., 2017). Consequently, the aforementioned stress induced changes can affect certain areas of the brain (e.g., amygdala, striatum, and the ventromedial-orbitofrontal cortices) involved in learning, reversal learning and decision making (Doll & Frank, 2009; Frank & Claus, 2006; Lighthall et al., 2011; Lighthall et al., 2013; Otto et al., 2013; Raio et al., 2017; Schroll & Hamker, 2013; Starcke & Brand, 2012).

It is possible that individual differences in the participants' response to acute stress may account for the inconclusive findings in the current study (Berghorst et al., 2013; Bogdan & Pizzagalli, 2006; Cavanagh et al., 2010; Preston et al., 2007; Salehi et al., 2010; Starcke & Brand, 2012). Moreover, these differences may result in acute stress being perceived as either a challenge or a threat, thereby causing neurophysiological changes to be either beneficial or detrimental to learning, reversal learning and decision making (Berghorst et al., 2013; Cavanagh et al., 2010; LeBlanc, 2009; Starcke & Brand, 2012).

4.4 Methodological Improvements and Contemplations

The main improvement of the present study is the utilisation of the STAI-S. The STAI-S can measure minor increases in state anxiety in response to acute stress. Furthermore, the STAI-S could potentially assess psychological stress. This is a crucial improvement as the assumed neuroendocrine responses don't always occur in response to the threat manipulation. Moreover, in contrast to the majority of previous research, the introduction of acute stress that is intrinsic to learning and decision making is a relatively innovative addition.

Physiological measures might prove useful to assess the typical neurophysiological responses to acute stress (e.g., α-amylase, cortisol levels, heart rate and skin conductance). The

lack of physiological measures could be a potential limitation. Research has demonstrated that neuroendocrine responses could potentially impair or improve learning, reversal learning and decision making (Berghorst et al., 2013; Cavanagh et al., 2010; LeBlanc, 2009; Starcke & Brand, 2012). This impairment or improvement is relative to the individual neurophysiological response. Furthermore, neuroimaging techniques such as electroencephalography, functional magnetic resonance imaging and positron emission tomography should be expended. Neuroimaging techniques are necessary to evaluate the assumed neurological mechanisms in response to acute stress. Moreover, a between groups experimental design would provide a control group necessary to avoid the potential residual effects of the previous condition. In addition, the utilisation of the trait scale (STAI-T) of the STAI should be used in conjunction with the STAI-S. It has been found that trait anxiety has been linked with stress reactivity in certain threat conditions. Trait anxiety could therefore be used to discern the effects of individual differences in response to acute stress.

4.5 Prospective Research Pathways

Future experiments should also investigate punishment and reward learning when observing the effects of acute stress on learning, reversal learning and decision making. The findings pertaining to the effect of threat manipulation on reward and punishment learning are inconsistent and should be explored in greater depth. Additionally, future research must also disassociate responders and non-responders to gain greater insight into individual stress reactivity.

4.6 Conclusions

In conclusion the results of the present study further contribute to finite body of research pertaining to the effects of acute stress on learning, reversal learning and decision making.

Moreover, the current study may support that acute stress is inducive to learning and in particular reversal learning relative to task difficulty. Furthermore, the current research supports a clear link between learning, reversal learning and decision making, in that participants differed in their application of acquired knowledge and not how they learned.

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Appendix A: STAI Form Y-1

SELF-EVALUATION QUESTIONNAIRE STAI Form Y-1

Please provide the following information:

Name_____Date_____S_____

Age_____ Gender (*Circle*) **M** **F** T_____

DIRECTIONS:

A number of statements which people have used to describe themselves are given below. Read each statement and then 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

STAIP-AD Test Form Y
www.mindgarden.com

State-Trait Anxiety Inventory for Adults Scoring Key (Form Y-1, Y-2)

Developed by Charles D. Spielberger in collaboration with R.L. Gorsuch, R. Lushene, P.R. Vagg, and G.A. Jacobs

To use this stencil, fold this sheet in half and line up with the appropriate test side, either Form Y-1 or Form Y-2. Simply total the scoring **weights** shown on the stencil for each response category. For example, for question # 1, if the respondent marked 3, then the **weight** would be **2**. Refer to the manual for appropriate normative data.

Form Y-1	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1.	4	3	2	1
2.	4	3	2	1
3.	1	2	3	4
4.	1	2	3	4
5.	4	3	2	1
6.	1	2	3	4
7.	1	2	3	4
8.	4	3	2	1
9.	1	2	3	4
10.	4	3	2	1
11.	4	3	2	1
12.	1	2	3	4
13.	1	2	3	4
14.	1	2	3	4
15.	4	3	2	1
16.	4	3	2	1
17.	1	2	3	4
18.	1	2	3	4
19.	4	3	2	1
20.	4	3	2	1

Form Y-2	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21.	4	3	2	1
22.	1	2	3	4
23.	4	3	2	1
24.	1	2	3	4
25.	1	2	3	4
26.	4	3	2	1
27.	4	3	2	1
28.	1	2	3	4
29.	1	2	3	4
30.	4	3	2	1
31.	1	2	3	4
32.	1	2	3	4
33.	4	3	2	1
34.	4	3	2	1
35.	1	2	3	4
36.	4	3	2	1
37.	1	2	3	4
38.	1	2	3	4
39.	4	3	2	1
40.	1	2	3	4

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Appendix B: Experiment Information Sheet

THE UNIVERSITY of ADELAIDE

SCHOOL OF PSYCHOLOGY
FACULTY OF HEALTH SCIENCES

THE UNIVERSITY OF ADELAIDE
SA 5005
AUSTRALIA

Information Sheet

Study Title

Individual differences in anxiety and learning: How well do you learn under stress?

Investigators

Dr Irina Baetu

Mr Steve Miller

Purpose of the Study

This project investigates how people learn to associate events that regularly occur together. This kind of learning is fundamental as it allows us to predict future events and plan our actions. Although everyone seems to be capable of such learning, there are known differences in the way people learn associations. For instance, some people are more prone to learn to associate neutral stimuli with pain or fear. Understanding how new memories are learnt is clinically relevant because some mental disorders, anxiety disorders in particular, are thought to develop as a result of an inborn propensity for fear learning. Furthermore, individuals who suffer from anxiety might respond to stress differently and might therefore learn differently in stressful conditions. We are interested in this latter aspect and will investigate how individuals learn in stressful versus safe conditions, and whether different learning patterns are associated with self-reported anxiety.

What Happens During the Study?

To investigate learning, participants are asked to complete a computerised task in which they learn whether various pictures frequently occur together. The task will be divided into several blocks. In some of the block's participants will be at risk of hearing bursts of loud sound while they learn, whereas in other blocks they will be safe, as no loud sound will be played during these blocks. **The bursts of loud sound are aversive; however, they should not cause any hearing damage.** Our aim is to study how people learn under conditions of stress (when an aversive loud noise is likely to happen) versus safety (when no loud noise will happen).

Furthermore, we will explore the relationship between learning and self-reported levels of depression, stress and anxiety, as well as certain personality traits. To assess their mood and personality, participants are asked to complete several questionnaires.

Location

The study takes place in the Hughes building room 240, School of Psychology, University of Adelaide, North Terrace Campus.

Who Can Participate?

Volunteers will be eligible for inclusion in this study only if all of the following apply:

- Aged 18 years or more
- Not suffering from an uncorrected visual or hearing disorder

Safety and Ethical Issues

The Human Ethics Committee of The University of Adelaide has approved this study (ethics approval number [redacted]. All potential participants will provide their written informed

consent before commencing the study. The risks of this study are considered minimal. Every effort will be made to ensure that the discomfort levels are kept to a minimum.

Leaving the Study

You are free to withdraw from the study at any time and for any reason. You are not required to explain your reasons to the study staff. You may also decide to withdraw any collected data. In this case, none of your data will be used for research purposes. Withdrawal from the study will not affect your involvement in any future research programs that you may wish to participate in.

Duration

The study lasts approximately 1.5 hours.

Confidentiality

All information collected about you from the study is completely confidential. Your results in this experiment will not be associated with your personal information at any point in time (e.g., in publications or presentations). Number codes rather than names will be used to assign identification.

Contact Information

If you have any questions about the study please feel free to contact Dr Irina Baetu (8313 6102, irina.baetu@adelaide.edu.au). Please see the attached independent complaints form if you have any concerns regarding the ethics of this research or would like to speak to someone independent of the project.

The University of Adelaide

Human Research Ethics Committee (HREC)

This document is for people who are participants in a research project.

CONTACTS FOR INFORMATION ON PROJECT AND INDEPENDENT COMPLAINTS PROCEDURE

The following study has been reviewed and approved by the University of Adelaide Human Research Ethics Committee:

Project Title:	**Individual differences in learning and anxiety**
Approval Number:	**H-17/14**

The Human Research Ethics Committee monitors all the research projects which it has approved. The committee considers it important that people participating in approved projects have an independent and confidential reporting mechanism which they can use if they have any worries or complaints about that research.

This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (see http://www.nhmrc.gov.au/publications/synopses/e72syn.htm)

1. If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the project coordinator:

Name:	**Dr Irina Baetu**
Phone:	**8313 6102**
Name:	**Professor Nick Burns**
Phone:	**8313 3965**

2. If you wish to discuss with an independent person matters related to:
   - making a complaint, or
   - raising concerns on the conduct of the project, or
   - the University policy on research involving human participants, or
   - your rights as a participant,

contact the Human Research Ethics Committee's Secretariat on phone (08) 8313 6028 or by email to hrec@adelaide.edu.au

Resources for psychological difficulties

During the experiment you will complete questionnaires that assess levels of depression, anxiety and stress. Should you need to speak to someone immediately regarding your psychological difficulties, please contact the services listed below:

Centre for Treatment of Anxiety and Depression (C.T.A.D.) – FREE SERVICE

- Experienced psychiatrists and psychologists, as well as trainee psychiatrists and psychologists under supervision.

30 Anderson St.,

THEBARTON SA 5031

Ph 8222 8100

Fax 8222 8101

Mensline (P) 1300 78 99 78 (W) www.menslineaus.org.au)

- 24hours, 7 days a week
- A dedicated service for men with relationship and family concerns (relationships, work, fathering, separation, stress)
- Counselling, information and referral service
- Confidential, staffed by trained professionals

Lifeline 13 11 14 (www.lifeline.org.au)

- 24hours, 7 days a week
- A mental health and self-help resource
- Phone line counselling, all day and night, every day of the year

- Also – you can download or phone order a self-help tool kit on a range of issues and you can call the service for referral information.

Furthermore, if you are currently experiencing serious thoughts of ending your life, you should immediately go to the emergency room of your local hospital to seek help.

Appendix C: Experiment Instructions Sheet

First screen

You will complete a series of questionnaires and a learning task that will last approximately one hour and a half. You will be provided with detailed instructions on the computer screen at the beginning of each task. The computer will inform you when the testing session is over.

Before you begin, please provide us with some information about yourself.

All of the information provided in this experiment will be kept anonymous and confidential.

First STAI

You are about to begin another mood questionnaire.

This questionnaire consists of twenty statements that people have used to describe themselves. Read each statement and then select the statement that indicates 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.

Second/Third/Fourth STAI

Before continuing with the learning task, please fill out the mood questionnaire again.

Reinforcement learning task instructions

Screen 1

You are about to begin the learning task. In this task you will be presented with different symbols, as in the example below. On every trial you will have to choose the symbols on the

right or left by pressing any of the keys on the right or the left side of the keyboard. For example, if you chose the flower symbol you would have to press any of the keys highlighted in blue below, and if you chose the fire symbol you would have to press any of the keys highlighted in red. You will only have 4 seconds to make a response, so don't waste too much time making a decision.

You will be informed whether your response was correct or incorrect. This feedback, however, will not always be consistent. For example, although the flower symbol below might be the better option, it will not always be followed by correct feedback. Your task is to discover which symbols are more likely to be correct and to maximise the number of correct choices.

To ensure that you respond as quickly as possible, keep the index of your left hand above one of the blue keys and the index of your right hand above one of the red keys.

Screen 2

The task will be divided into several blocks. In some of the blocks you will be at risk of hearing a loud burst of an aversive sound. That is, bursts of loud sound could happen any time during a block that begins with the warning message shown in the left figure below. The background colour of the screen will remain pink in between trials (when no pictures are shown) to remind you that a loud sound could happen any time.

You will be safe in the other blocks that will begin with the message shown in the figure on the right. That is, no sound will be played during these blocks. The background colour of the screen will remain grey in between trials to remind you that you are safe.

Regardless of whether a loud sound might or might not occur, try to remember which pictures are associated with correct or incorrect feedback and try to respond as quickly and accurately as possible throughout the task.

You will be asked to complete the mood questionnaire that you have just completed three more times during this task. That is, the learning task will be interrupted three times allowing you to complete the questionnaire before continuing it.

If you have understood these instructions, click Start to begin the task. If you have any questions, please ask the experimenter before clicking Start.

Test instructions

It's time to test what you've learned during the learning task! During this set of trials, you will NOT ALWAYS receive feedback ('Correct!' or 'Incorrect') to your responses. If you see new combinations of symbols in the test, please choose the symbol that 'feels' more correct based on what you learnt during the training sessions. If you're not sure which one to pick, just go with your gut instinct!

So, remember to continue responding even though you will not receive feedback after every prediction.

You will not hear any loud sound during this test phase.

Press any key to continue.

Second (threat or safe) condition

You will now be presented with new symbols and your task is still to learn to choose the symbol that is most likely to be correct.

A loud sound could be played any time during the next few minutes.

Or

You are safe for the next few minutes. No loud sound will be played.

Appendix D: Consent Form

SCHOOL OF PSYCHOLOGY
FACULTY OF HEALTH SCIENCES

THE UNIVERSITY OF ADELAIDE
SA 5005
AUSTRALIA

Consent Form

Study Title

Individual differences in anxiety and learning to fear: How well do you learn under stress?

Investigators

Dr Irina Baetu

Mr Steve Miller

1. The nature and purpose of the research project has been explained to me. I understand it and agree to take part.

2. I understand that I will not directly benefit from taking part in the experiment.

3. I understand that, while information gained during the study may be published, I will not be identified, and my personal results will remain confidential.

4. I understand that I can withdraw from the study at any stage.

Name of Participant:……..

(FIRST) (MIDDLE) (SURNAME)

Signed:…… Dated:…….

I certify that I have explained the study to the volunteer and consider that he/she understands what is involved.

Name of Investigator:……

Signed:…… Dated: ……