The Impact of Stress on Learning: Exploring How Stress Changes Learning about Positive and Negative Outcomes and the Role of Anxiety

Alex Pamment

This thesis is submitted in partial fulfilment of the Honours Degree of Bachelor of Psychological Science (Honours)

School of Psychology

University of Adelaide

October 2018

Word Count: 8,791

Table of Contents

List of Figures

List of Tables

Abstract

Stress has a strong influence on learning, particularly about positive and negative outcomes. However, it is unclear whether stress enhances or disrupts learning about positive and negative outcomes due to inconsistent findings in the literature. There is a possibility that stress affects learning from appetitive and aversive prediction errors. Prediction error refers to the discrepancy between observed and expected outcomes. This discrepancy is considered to be crucial to generate new learning. To test this, a blocking design was used to assess learning from prediction errors in stressful versus non-stressful conditions. A blocking design consists of learning about a stimulus (e.g. X) that is reduced if it is paired with another stimulus (e.g. A) that is a better predictor of the outcome (e.g. A → outcome; AX → outcome). The outcome is not surprising on AX trials because A has already been associated with the outcome; therefore the prediction error is small and this reduces learning about X. X is a redundant predictor of the outcome, so learning about it should be blocked. Results show that learning about the blocked stimulus was reduced under threat but only for positive outcomes. This seems to indicate that learning is streamlined under threat where only relevant stimuli with positive outcomes are focused on. In safe conditions and for negative outcomes, more general learning is used.

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 material previously published except where due reference is made. I give permission for the digital version of this thesis to be made available on the web, via the University of Adelaide's digital thesis repository, the Library Search and through web search engines, unless permission has been granted by the School to restrict access for a period of time.

Alex Pamment

October 2018

Acknowledgements

Firstly, I would like to thank my incredible supervisor Irina Baetu. Her support and guidance made this entire experience much less terrifying and stressful than it may have been otherwise and for that I am extremely grateful. She has a brilliant wealth of knowledge for this area of research and her willingness to help me through diving into this world of theory was invaluable.

I would also like to thank my partner Lauren for supporting me through this stressful time and I could not have made it through without him. A big thanks to my friends Sarah, Ellie, and Sam for being supportive, keeping my sane, and being willing to help where they could.

1 Introduction

1.1 Learning under Stress

Stress is a regular occurrence in the everyday lives of all humans, presenting itself in the potential threats experienced in emotionally arousing experiences. Numerous diverse events can become stressors, ranging from a small inconvenience to a major disrupting life event (Joels, Pu, Wiegert, Oitzl, & Krugers, 2006). In a survey, 80% of Americans reported they experienced at least a moderate level of stress on a daily basis (Lighthall, Gorlick, Schoeke, Frank, & Mather, 2013). Stress is also a highly subjective experience which is not perceived equally by different individuals. A specific event may not be perceived to be equally stressful by different individuals; therefore, understanding what mental processes are affected by stress could prove useful for prediction how people react in stressful situations (Ness & Calabrese, 2016).

The typical occurrence for stress is when a demand exceeds the expected capacity of the person, particularly occurring in unpredictable and uncontrollable situations (Starcke & Brand, 2016). Physical effects of stress can include elevated heart rate, blood pressure, and galvanic skin response (Ness & Calabrese, 2016). A situation is considered to be stressful based on the complex interactions between the prefrontal cortex, hippocampus, and amygdala in the brain. These structures are involved in appraising situations and modulating adapting behaviour (Ness & Calabrese, 2016). The hypothalamus-pituitary-adrenal axis (HPA) is also considered to play a major role in the stress response, which is activated by elevated levels of cortisol in the blood (Petzold, Plessow, Goschke, & Kirschbaum, 2010). All of these neural structures are involved in learning and decision making, therefore stress not only has physiological effects but also an impact on our decision making ability. However, so far it is uncertain how cognitive abilities are affected by stress. The aim of this research is to further investigate the effects of stress on learning and memory.

Stress has a strong influence on learning, which is diverse and varies depending on timing, intensity, stimulus valence, and emotional content. In some situations, stress can impair learning, while in others it can enhance learning and memory (Aberg, Clarke, Sandi, & Herzog, 2012; Navarro-Frances & Arenas, 2014) Learning is only enhanced under stress when it is experienced in the context and around the time of the event that needs remembering. It is generally accepted that stressful events are very well remembered with high salience. Animal studies have demonstrated that stress can facilitate and perhaps be indispensable for learning and memory (Joels et al., 2006). Stress being paired with a learning task is typically considered to facilitate the consolidation of the event. However, stress has also been associated with impaired performance, leading to an unreliable memory for a stressful event (Joels et al., 2006).

It is argued that stress enhancing or impairing learning and memory may depend on whether the stressor is experienced closely linked in time and within the context of the information being learned. The relationship between stress and learning has been argued to be an inverted u-shaped dependency. In this, moderate stressors can improve memory while high and low level stressors may impair learning (Joels et al., 2006); (Navarro-Frances & Arenas, 2014). This idea was originally argued by Yerkes and Dodson (1908) where they used the inverted u-shape theory to propose that cognitive performance in learning is best when the individual is under optimal stress; this being that performance would be impaired above or below the optimal stress level and optimal at the mid-point (Salehi, Cordero, & Sandi, 2010). While this theory has been criticised for his potential lack of validity, it proposes an idea for how stress and learning can have an interesting and complicated relationship that needs further study.

More importantly, stress might influence learning, which in turn can influence decision making. People make decisions based on the perceived likelihood of whether the outcome will be positive or negative, which relies heavily on previous learning and expectations (Lighthall et al., 2013). Learning about alternative options and making choices under stress is common; especially considering that learning about decision options can elicit stress, particularly in the case of high-stake choices. If stress affects learning, then it could lead to poor decision making. For example, stress can lead to a heavy reliance on cues or choice options that have been associated with high risk and immediate rewards, which is not always an optimal strategy (Starcke & Brand, 2016).

1.2 Positive and Negative Learning under Stress

While it has been addressed that stress has an effect on learning, it is essential to look at specific effects that are dependent upon the valence of the outcome or consequences of an action. Stress may have different effects on how individuals perceive and respond to positive or negative outcomes in their environment (Treadway et al., 2017). The processing of positive and negative outcomes is crucial to decision making, as the anticipation of which outcome will occur guides the choices we make (Starcke & Brand, 2016). The literature on the effect of stress on learning about positive and negative outcomes, however, has yielded inconsistent results.

1.2.1 Learning about Negative Outcomes.

In a study by Petzold and colleagues (2010) looking at the effects of psychosocial stress on feedback based learning, it was found that there was a reduced use of negative feedback in a stress condition. The Trier Social Stress Test (TSST) was used as the stress manipulation in the stress condition, which involved a period of anticipation which was followed by participants undertaking a free speech and mental arithmetic test in front of an evaluative committee. During this speech, participants were videotaped and spoke into a microphone. Participants then undertook a probabilistic selection task where they had to learn to choose stimuli that were followed by favourable outcomes (i.e. positive feedback) over less favourable ones. They found that during the stress condition, learning from negative feedback (i.e., learning to avoid selecting the stimuli that led to a less favourable outcome) was significantly impaired when compared to a no-stress condition. A study by Harrison and colleagues (2016) also found reduced learning about negative outcomes in their study looking at stress-induced inflammation and its effects on sensitivity to positive and negative feedback in a reinforcement-learning task.

However, Cavanagh, Frank, and Allen (2011) instead found that social stress enhanced learning about negative outcomes in high-stress vulnerable individuals and reduced learning about negative outcomes in less vulnerable individuals. Using an uncomfortable social evaluative stress condition and a probabilistic learning task, they looked at trait level sensitivity to negative outcomes and negative affect. The stress condition was similar to the TSST and involved creating a socially evaluative environment with overt displays of exposed failure. The probabilistic learning task was too difficult for participants to perform well and was intended to add to the feeling of uncontrollability. They found that these variables moderated the ability to learn to seek positive and avoid negative outcomes under stress. More specifically, trait level punishment sensitivity and state-related negative affect were found to moderate the ability to learn to seek reward and avoid punishment during social stress. This was demonstrated by lower trait-level punishment sensitivity predicting improved reward learning and reduced punishment learning; the opposite was found in individuals with higher punishment sensitivity.

1.2.2 Learning about Positive Outcomes.

A number of studies have found stress disrupting effects on learning about positive outcomes. Berghorst and colleagues (2013) grouped their participants according to their cortisol reactivity to stress and self-reported anxiety levels. High responders (the stress reactive group) demonstrated reduced accuracy on positive outcome trials in a stress condition compared to a no-stress condition. This suggests that individuals with high cortisol reactivity to stress learned less from positive outcomes under stress.

Similarly, in a study conducted by Bogdan and colleagues (2011) an electric shock stressor and a probabilistic reward learning task was used and they found that the stress manipulation disrupted learning about positive outcomes. Consistent with this, de Berker and colleagues (2016) found that under stress conditions using a cold pressor test (participants submerge their arm in water for 3 minutes - for stress conditions, the temperature ranges from 0-1 degree Celsius; in the control condition it ranges from 24-27 degrees Celsius) there was impairment in learning about positive outcomes and an improvement in learning about negative outcomes. Similar results were found by Cremers and colleagues (2015), who investigated sensitivity to social reward using a social incentive delay task (participants predict a possible outcome of either happy or angry faces). They found that the usual preference for positive outcomes (social reward) in this task was absent in social anxiety disorder participants in comparison to control participants in a stress condition.

Finally, a study by Lighthall and colleagues (2013) did find enhanced learning about positive outcomes, which is inconsistent with the studies reviewed above. They tested probabilistic learning with a cold pressor stress manipulation. Their findings showed that stress enhanced learning about associations with positive outcomes but did not enhance learning about negative outcomes.

It is clear that there are conflicting findings in regards to the effects of stress on positive and negative learning. Looking at the literature presented, different studies found all possible results, namely that stress enhances or disrupts learning about negative and positive outcomes. This makes it difficult to understand how stress can impact individuals and which types of learning are disrupted under stress and which are enhanced. Further research is therefore needed to explain the effects of stress on learning.

1.3 Prediction Error in Learning and Theory

Theories of learning can be very useful for understanding the effects of stress on performance. The most popular and best supported theories of learning use the concept of prediction error to explain learning.

Prediction error refers to the detection of a mismatch between expected outcomes and the outcomes which are observed. When an individual enters a situation, they develop expected outcomes for what will occur, and when these differ from what actually happens, prediction error occurs. This is considered to be a critical precursor for the forming of new stimulus-outcome associations (Robinson, Overstreet, Charney, Vytal, & Grillon, 2013). Learning about situations is influenced directly by prediction errors, which decrease gradually until an individual's predictions match the expected outcome (Tobler, O'Doherty J, Dolan, & Schultz, 2006). This forms the basis for many learning models (e.g., Rescorla & Wagner, 1972).

There is extensive evidence that prediction error is essential to learning. Tobler and colleagues (2006) looked at this in relation to positive outcome prediction. They found that prediction error plays an important role in relation to learning about stimulus-reward associations. They found that in humans brain responses to positive outcomes in orbitofrontal cortex and ventral putamen are proportional to the prediction error. Their findings were in line with prediction error learning theory.

Robinson and colleagues (2013) argue that the effect stress has on learning is modulated by prediction error. They argue that stress can increase a key learning mechanism in the mismatch between an expected and an observed aversive outcome; the greater the mismatch between these, the greater the prediction error which leads to greater learning. Their results suggest that stress significantly increases an aversive prediction error signal, therefore specifically increasing learning about negative outcomes. This suggests that learning about aversive, or negative, outcomes may be modulated by the prediction error stage. However, they found no significant effect for appetitive prediction error signals, suggesting that stress significantly increases only aversive prediction error signal, providing a unique account for how threat associations are learnt about differently under stress.

In principle, predicting threats under stressful conditions is useful because learning can allow an organism or individual to avoid threats and place themself out of harm's way. But stress has also been found to influence learning about positive outcomes, so it may affect learning from positive, or appetitive, prediction errors as well.

Consistent with this, Treadway and colleagues (2017) reported that stress influences reward, or positive, prediction error signals during reinforcement learning. They induced stress by using the Maastricht Acute Stress Test (MAST) and the Montreal Imaging Stress Task (MIST) in two separate sessions. They measured plasma interleukin-6 levels (IL-6), which has been known to be responsive to stress They found that stress-induced increases in IL-6 were associated with a decrease in ventral striatal reward prediction error signalling during a learning task.

Prediction error therefore could provide an important basis for investigating the role of stress in learning. It could explain how stress modulates negative and positive outcome learning. However, the studies reviewed above reported results are inconsistent, some demonstrating an effect of stress on brain responses to negative prediction errors, and others on positive prediction errors. To get a better understanding of this issue, we will use a blocking paradigm which is a good way of testing learning from prediction errors and has not been used in this field before.

1.4 The Blocking Effect and Prediction Error

When looking at the role of prediction errors in learning, the defining paradigm to demonstrate this is through blocking. The blocking effect occurs when a novel stimulus is blocked from being learned about when it is associated with a predicted outcome (Tobler et al., 2006).

The blocking effect was first discovered by Kamin (1969) in rats. He observed that a stimulus that was previously paired with an unconditioned stimulus (e.g., a light that always preceded food; Light → food) could block subsequent associations of a second stimulus to the unconditioned stimulus (e.g., Light + Tone → food would result in poor learning that the tone is followed by food) Kamin argued that blocking (i.e. poor learning about the tone) occurs because of a requirement for surprise in learning and that no learning will occur when the unconditioned stimulus is fully predicted (in this case, because the light is a good predictor of the food) This idea inspired the prediction error theory proposed by Rescorla and Wagner (1972), as well as many subsequent models (Terao, Matsumoto, & Mizunami, 2015).

The Rescorla Wagner model (1972) proposes that changes in associative strength are determined by how much discrepancy there is between the expected and predicted outcome, which creates the prediction error (Boddez, Haesen, Baeyens, & Beckers, 2014). When looking at the blocking effect, the pretrained stimulus generates an expectation of the outcome so the blocked cue cannot form an association with the same outcome (Boddez et al., 2014). Using the light and tone example, if food (the outcome) repeatedly follows the light, this will result in an association (Light → Food). If later food is given after showing a light and playing a tone (Light + Tone → Food), learning about the tone will be blocked. Learning about the blocked cue (tone) is 'blocked' by the pretrained stimulus (light) because whenever they occur, the light generates an expectation that food will occur, so the occurrence of the food is never surprising. Because of this lack of prediction error, the tone is not learned to be associated or predictive for the outcome (food).

Studies looking at the blocking effect support the prediction error theory put forward by Rescorla and Wagner. Terao, Matsumoto and Mizunami (2015) studied the blocking effect in crickets and found validity for the prediction error theory and evidence of blocking. In another study by Tobler and colleagues (2005) they found that learning depends crucially on the presence of a prediction error and that human appetitive learning can be blocked.

The current study will use blocking designs to test learning from positive and negative prediction errors.

1.5 Anxiety and Individual Differences

Studying individual differences in learning under stress is essential, particularly to understand the effects of anxiety on decision making. An event that is appraised and considered stressful by one individual may not be perceived the same way by another individual. Even when a stressor is similarly appraised, different individuals may use different coping strategies to deal with the situation. Stressors that involve anticipation of adverse events may be related to anxiety (Anisman & Matheson, 2005). Stress and anxiety are interrelated as stress throughout life can critically contribute to the development of anxiety and other disorders (Campos, Fogaca, Aguiar, & Guimaraes, 2013). Importantly, trait anxiety has been identified as a key predictive factor of inter-individual differences in performance in learning tasks, as well as the role of stress in learning and memory (Navarro-Frances & Arenas, 2014).

Anxiety disorders are characterised by an overgeneralization of fear to realistically non-dangerous stimuli as well as uncontrollability over stressors (Pizzagalli, Bogdan, Ratner, & Jahn, 2007). This fear generalisation is central to what makes anxiety disorders so impairing. Fear generalisation occurs when a fear response becomes paired with a broad set of stimuli rather than the specific stimulus responsible (Boddez et al., 2012). This may be due to lack of selective threat appraisal where all perceptual features and stimuli present at a traumatic event are considered high threat and become fear-eliciting A blocking design can be used to assess the tendency to generalise fear responses: if participants learn to fear the blocked stimulus in a blocking design despite the fact that it is a redundant predictor of the outcome, then this increases the number of stimuli that are associated with fear.

Consistent with this idea, a study by Boddez and colleagues (2012) demonstrated a lack of selective threat appraisal and a deficit in blocking in individuals high in trait anxiety. This effect was, however, not replicated in a subsequent study (Arnaudova et al., 2013). Furthermore, studies that have investigated the effects of anxiety on learning under stress found that stressors have a larger effect on individuals with anxiety. Navarro-Frances and colleagues (2014) found that the trait anxiety of mice significantly altered their response in a conditioning task, impairing their performance. Grillon (2002) also found that deficits in performance in a differential conditioning task were associated with anxiety. Finally, Shackman and colleagues (2006) found that anxiety disrupted learning performance under stress conditions.

The relationship between anxiety and blocking is still poorly understood and previous studies on anxiety only assessed blocking with negative outcomes. It is also unclear how stress manipulations interact with trait anxiety to influence learning outcomes. So this project will test whether individual differences in anxiety can predict how learning in a blocking design is affected by a stress manipulation.

1.6 Hypotheses

Given the mixed results regarding the relationship between stress and learning, this project will investigate whether prediction error learning differs under stress when the outcome is positively or negatively valanced. Learning from prediction errors will be assessed via the blocking effect, as it is a robust measure of prediction error processing.

Additionally, the role of anxiety in learning under stress will be investigated. As anxiety may enhance the effects of stress, it is hypothesised that more anxious individuals will show a larger effect of stress on learning from prediction errors, i.e., a larger discrepancy when comparing learning under stress and learning under normal conditions.

2 Method

2.1 Participants

Twenty-two participants took part in the study. The age of the participants ranged from 18 to 56 years (mean = 23.8), and 14 were female. All were first year Psychology students at the University of Adelaide recruited using the Research Participation System (SONA). They volunteered to participate in the study in return for course credit. The selection process was restricted to those over 18 years of age and required participants to not be suffering from an uncorrected visual or hearing disorder.

2.2 Apparatus and Measures

Testing was conducted on Macintosh 21-inch iMac computers. Participants used keyboard and mouse to complete the computerised test and wore headphones for the entire duration of the experiment.

2.2.1 Anxiety Testing.

Three tests were used to measure anxiety in participants before they underwent the learning task. The Emotional Dot Probe, the Depression Anxiety Stress Scale, and the State Trait Anxiety Scale were chosen due to their strong validity and reliability, allowing a more reliable assessment of the anxiety of participants.

Emotional Dot Probe (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002).

The first measure was the emotional dot probe, used to measure attentional bias toward emotionally negative information. This test is being used to measure anxiety due to evidence linking anxiety with negative attentional bias (MacLeod et al., 2002). The emotional dot probe is useful for measuring differences in anxious and non-anxious individuals through this attentional bias link (Torrence & Troup, 2018). Trials begin with a cross appearing for 500ms, followed by two words for 200ms. These words appear on either side of the cross; one word being neutral and the other negative. A dot then appears on either the left or right where one of the words previously appeared. Participants are asked to report where the dot appeared; either left ('A') or right ('L') with 3 seconds to respond (MacLeod et al., 2002). Trials are separated by 500ms and the location of the neutral and negative word differs per trial. The dot replaces the neutral or negative word equally often. There were 96 trials and a dot probe score is calculated by subtracting the reaction time (RT) to the dot when it replaced the threat word from the RT when the dot replaced the neutral word (RTneutral - RTthreat). Anxious participants should be able to detect the dot faster when it appears in the spatial vicinity of the negative words as opposed to the neutral words, which would result in larger RT difference scores. In contrast, non-anxious participants should detect the dot more slowly when it appears in the spatial vicinity of the negative words (MacLeod et al., 2002).

DASS-21 - Depression Anxiety and Stress Scale (Lovibond & Lovibond, 1993).

The second anxiety measure undertaken by participants was the Depression Anxiety and Stress Scale (DASS-21). The scale is a self-reported measure used to assess symptoms of depression, anxiety, and stress by asking the participant to reflect on the previous week. Each of 21 questions has four answer options, reflecting increasing severity (Lovibond & Lovibond, 1995). Scores are obtained for each of the factors (depression, anxiety, or stress), as well as an overall score. This test was used because of its strong validity and reliability for Australian populations (Oei, Sawang, Goh, & Mukhtar, 2013), as well as for differentiating anxiety from the other factors it measures with high internal consistency (Page, Hooke, & Morrison, 2007; Lovibond & Lovibond, 1995).

State Trait Anxiety Scale (Spielberger, Gorsuch, & Lushene, 1970).

The third measure for anxiety was the State Trait Anxiety Scale. This self-report scale measures anxiety across two levels, state and trait (Bados, Gomez-Benito, & Balaguer, 2010). Both state and trait had 20 items with 40 items in the test overall and participants rate their responses from 1-4. Trait anxiety (STAI-T) measures an individual's disposition to respond with anxiety in threatening situations, while state anxiety (STAI-S) measures an individual's anxiety at a particular moment (Bados et al., 2010; Vagg & Spielberger, 1980). The trait scale focuses on frequency of anxiety, while the state scale focuses on the symptoms and absence of anxiety (Vagg & Spielberger, 1980). This measure was used as it has strong empirical support for the state and trait factors being independent and meaningful as well being a valid method for measuring anxiety (Spielberger & Vagg, 1984; Bados et al., 2010).

2.2.2 Learning Task.

The learning task involved learning which neutral stimuli (the cues) predicted happy or fearful faces (the outcomes). For each trial, the participant was shown one or two picture cues and they had to then guess which type of outcome (happy face or fearful face) would occur. Participants indicated their guess on a sliding scale that ranged from -100 to 100. The two ends of the scale were labelled 'certain fearful' and 'certain happy', respectfully. Participants were then shown either a happy or fearful face for 1 second. The experiment was split into a training phase and a test phase; the main difference being the test phase did not provide feedback to the participant on whether they guessed which face would appear correctly. That is, on test trials participants were presented with individual cues and made predictions without being presented with either happy or fearful faces following their prediction. The happy and fearful faces were sourced from the Warsaw set of emotional faces (Figure 1) (Olszanowski et al., 2014). These were chosen due to evidence that seeing a genuine happy or fearful face will evoke feeling those emotions in the participant. This formed the basis for our positive and negative outcomes.

*Figure 1.*Example of happy (top) and fearful (bottom) faces used as outcomes in the learning task.

2.2.3 Blocking.

A blocking design was used which involves presenting a stimulus (A) that predicts an outcome on its own with a target stimulus (B). A predicts the happy face on every trial, including when it is presented by itself. A and B are also paired with the happy face. In principle, B should fail to generate a substantial prediction error because A already has been associated with the outcome, and learning about it should be blocked. A and B are tested alongside C and D which also predict the happy face. C and D represent control cues as neither is presented by itself. During the test, participants are asked to guess which face would follow each individual cue, however, unlike the testing trials, no feedback is provided (i.e., no outcome was shown following the participant's prediction). If they report that C and D are more predictive of the happy face than B, a blocking effect has occurred. A blocking score is generated based on how much more predictive C and D are considered to be compared to B (CD - B).

This design was also repeated with fearful faces using G as the blocking stimulus and H as the paired blocked stimulus (see Table 1). I and J were control cues similar to C and D. Blocking scores were calculated based on the difference between ratings at test for I and J relative to H (IJ - H).

Table 1.

Summary of training and test trials and blocking design.

Training phase		Test phase	
Cues	Outcome	Cues	Kind of Cue
A	Happy face	A	123
AB	Happy face	B	Blocked cue
CD	Happy face	C	Control cue
		D	Control cue
E	Happy face	E	
EF	Fearful face	F	
		G	
G	Fearful face	H	Blocked cue
GH	Fearful face	I	Control cue
IJ	Fearful face	J	Control cue
		K	
K	Fearful face	L	
KL	Happy face		

Filler trials were also used which were set up to appear similar to AB and GH trials using EF and KL. One of the cues in these pairs predicted a happy (E) or fearful (K) face on their own, but when paired with another stimulus the outcome was opposite (EF -> fearful face; KL -> happy face). This was to ensure that participants would not learn compound rules for paired stimuli, i.e., that a pair will have the same outcome as one of its elements. Each training trial type was presented six times randomly and intermixed with the others, and each test trial type was presented once (Table 1).

2.2.4 Stress/Safe Conditions.

The study used a within-subjects design so the safe-stress manipulation was administered to each participant in a single testing session. The learning task was split into four blocks of trials. The blocks were either ordered safe-stress-safe-stress or stress-safe-stress-safe. The order of the blocks was counterbalanced across participants. Participants were informed at the beginning of the experiment there was a chance they may hear a loud burst of white noise during trials with a red background. The safe condition displayed a grey background in between trials that was displayed for 1.5 seconds. This informed participants that they were safe, i.e., that no sound would be played. In the stress condition, this background was red and informed participants that they were now at risk of hearing a burst of white noise (see Figure 2 for example trials). These two backgrounds comprised our stress and safe conditions in a repeated-measures design.

During the stress blocks, the 85-dB burst of white noise (0.7 seconds) only played 3 times in the first stress block and twice in the second stress block. The purpose of this manipulation was to create an expectation for something aversive to occur at any time and create stress without participants being excessively distracted by the white noise being played too frequently.

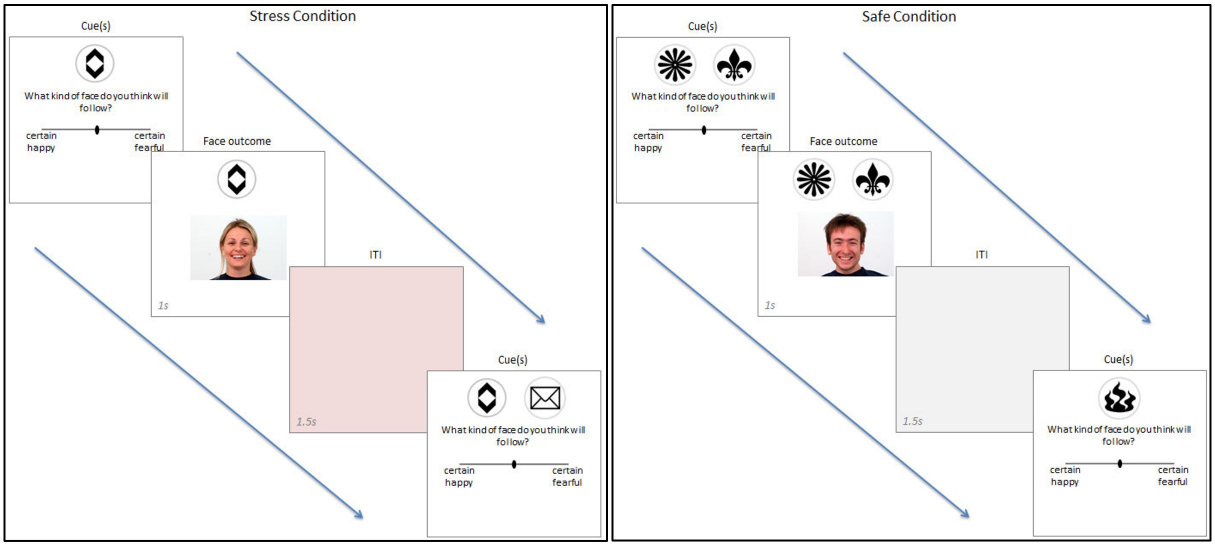

Figure 2. Examples of trials in the learning task during stress blocks (left) and safe blocks (right). The learning stimuli (cues) were first presented along with a sliding scale used to predict which type of face would follow. After participants made their prediction, the outcome (happy or fearful face) was displayed. After a 1.5 second inter-trial interval (ITI) the next trial began.

Two blocking scores were calculated for each block (one for positive outcomes and one for negative outcomes) and the scores obtained from the two blocks in each condition (stress and safe) were averaged. This provided four blocking scores, one for positive outcomes (C/D - B) and one for negative outcomes (I/J - H) in each of the two conditions (stress and safe). This repeated-measures 2x2 design allowed us to test the blocking effect with two types of outcome (positive, negative outcomes) in two threat conditions (safe, stress).

2.2 Procedure

Participants were first briefed on the contents of the experiment and the tests involved (Appendix A). After giving informed consent (Appendix B), they were assigned an identification number to provide anonymity and were shown to a testing computer. Participants were first asked for demographic information (gender, age) and then they undertook the mood tests followed by the learning tasks. These were completed in the following order: Emotional Dot Probe, DASS-21, State Trait Anxiety Scale, Learning task.

3 Results

3. 1 Overview

Anticipated findings are that there will be a difference in blocking when comparing learning under stress versus safe conditions. This is being investigated with positive outcomes (Aim 1) and negative outcomes (Aim 2). Additionally, the difference in learning in safety and stress conditions is expected to be more pronounced for anxious participants (Aim 3).

3.2 Descriptive Statistics

The experiment included 22 participants, the means and standard deviations for their mood and blocking scores are summarised in Table 2.

Table 2.

Summary of statistics for the mood scores and the blocking scores.

	Mean	Standard Deviation
Mood measures		
Dot Probe	-5.86	16.51
DASS-21	17.23	8.75
STAI	95.18	21.81
Blocking scores		
Positive Outcome Stress	26.80	46.10
Positive Outcome Safety	-5.41	26.07
Negative Outcome Stress	6.36	40.32
Negative Outcome Safety	-3.23	32.20

3.3 Aim 1: Blocking Scores for Positive Outcomes under Stress vs. Safety

A 2x2 repeated-measures MANOVA was conducted on the positive outcome condition with two factors, type of cue (Blocked v Control) and condition (Stress v Safety). MANOVA was chosen as it is more robust to normality assumption violations. There were no significant main effects, maximum $F(1,21) = 2.8$, $p = 0.108$, $\eta^2 = 0.12$. However, a significant interaction was found, $F(1, 21) = 11.2$, $p = 0.003$, $\eta^2 = 0.348$. As seen in Figure 3, the blocking effect was larger in the stress condition compared to the safety condition.

Due to this significant interaction, paired samples t-tests were conducted to test whether there was significant blocking in the safety and stress conditions. For the safety condition the results were not significant, $t(1, 21) = 0.972$, $p = 0.341$, CI^{95} [-6.2 17.0]. This indicates that there was not a significant difference between the control and blocked cues, so blocking did not occur in this condition. In the stress condition, there was a significant difference between the control and blocked cues, $t(1, 21) = 2.726$, $p = 0.012$, CI^{95} [6.4 47.2]. So a significant blocking effect did occur in the stress condition.

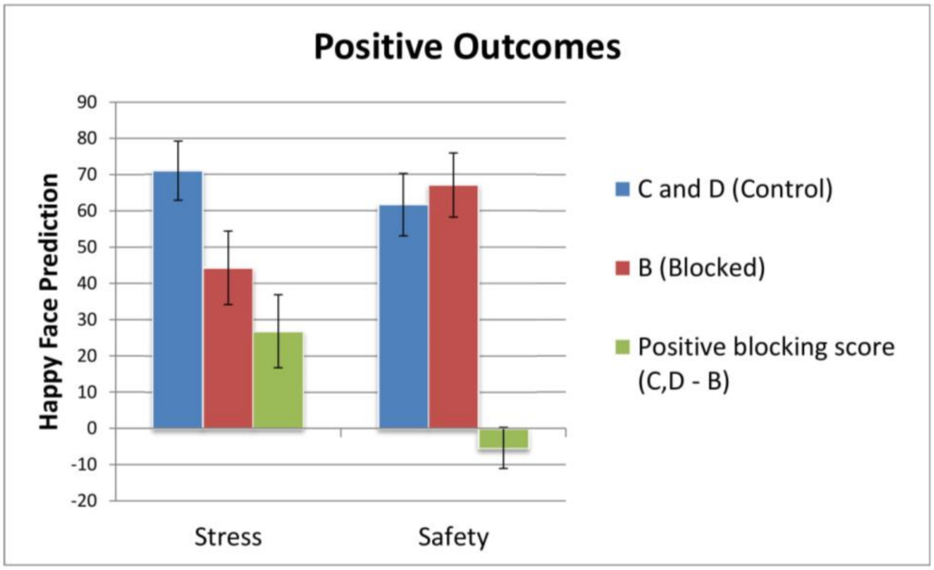

Figure 3. Mean happy face predictions made at test for the control and blocked cues in the stress and safety conditions. The average of the two control cues is plotted. The magnitude of the blocking effect is reflected in the size of the blocking scores.

3.4 Aim 2: Blocking Scores for Negative Outcomes under Stress v Safety

For the negative outcomes, a repeated-measures MANOVA was again conducted with the same 2(Blocked v Control) x 2(Stress v Safety) design. There were no significant main effects nor a significant interaction, maximum $F[1, 21] = 3.6$, $p = 0.069$, $\eta^2 = 0.148$. As there was no significant difference between the control and blocked cues, no significant blocking occurred for negative outcomes in either condition (see Figure 4).

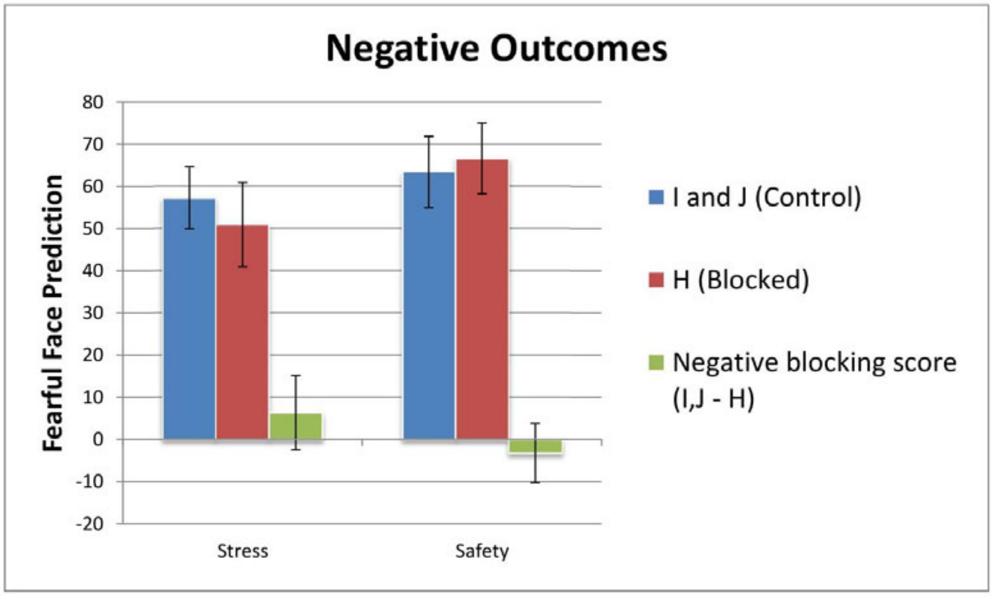

Figure 4. Mean fearful face predictions made at test for the control and blocked cues in the stress and safety conditions. The average of the two control cues is plotted. The magnitude of the blocking effect is reflected in the size of the blocking scores.

3.5 Aim 3: Relationship between Blocking and Anxiety

For each participant, we calculated the difference between the positive blocking scores under stress vs. safety conditions. To examine whether anxiety predicts the effect of the stress manipulation on the blocking scores, we correlated these difference scores with anxiety. There were 3 measures of anxiety; to determine an overall anxiety score we computed the average of the *z*-scores for the dot probe, DASS-21 and STAI.

Spearman rank correlations are reported in addition to Pearson r to ensure the results reported are robust. Anxiety was positively correlated with the difference in blocking scores for positive outcomes, Pearson $r = 0.46$, $p = 0.030$; Spearman $\rho = 0.51$, $p = 0.015$. This suggests that anxious individuals in our sample also had higher positive blocking scores in the stress condition relative to the safe condition. That is, the effect of the stress manipulation on positive outcomes was more pronounced in anxious individuals (see Figure 5).

A similar analysis was performed on the blocking scores for negative outcomes, correlating anxiety with the difference between the blocking scores in the stress versus safe conditions. There was, however, no significant correlation, Pearson $r = -0.07$, $p = 0.749$; Spearman $\rho = -0.15$, $p = 0.505$, potentially because there was no significant blocking effect for negative outcomes in either condition.

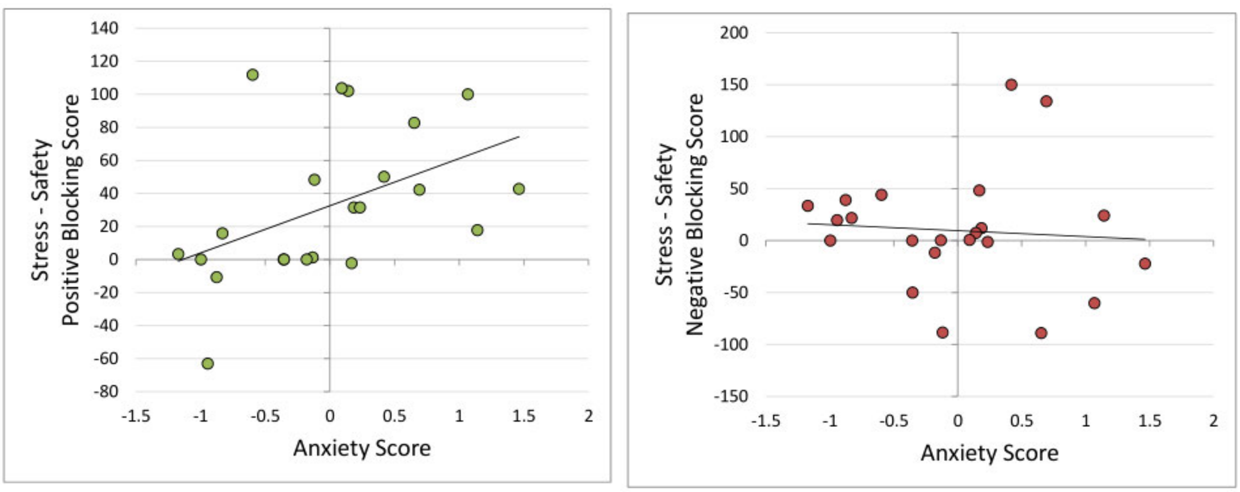

Figure 5. Scatter plots showing the relationship between anxiety scores and the difference in blocking scores in stress vs. safe conditions for positive outcomes (Left) and negative outcomes (Right).

3.6 Summary

No significant results were found for negative outcomes. This indicates that there was no difference between learning in stress or safety conditions, as well as no significant blocking present for negative outcomes.

There were however significant differences for positive outcomes. In the stress condition, more blocking was present and a significant difference between the control and blocked cue was present. There was no difference between the control and blocked cues in the safety condition. This suggests that the stress manipulation enhanced blocking for positive outcomes but not for negative outcomes.

Furthermore, it was found that anxiety correlates with the learning difference observed for positive outcomes, indicating a relationship between anxiety and the impact of the stress manipulation. Anxious participants showed a larger difference between the blocking scores when comparing the stress and safety conditions.

4 Discussion

The current study investigated the impact stress has on learning. Primarily we looked at whether learning under stress is being disrupted or enhanced and how this differs for different outcomes (positive or negative). If an outcome leads an individual to feel happy, does this change how they learn about it under a stressful condition than if the outcome made them feel fearful? Positive and negative outcomes can evoke different results, which makes it important to determine the effects of stress on both.

To look at how stress affects learning, the difference between learning in a stressful condition and learning in a safe condition was evaluated. Blocking scores were used to determine whether learning from prediction errors differ between conditions. According to the most dominant type of theory, learning occurs depending on whether there is a discrepancy between what an individual expects an outcome to be and the outcome they observe, i.e., depending on whether they experience a prediction error (Robinson et al., 2013). Blocking allowed us to measure this efficiently, as a high sensitivity to prediction errors would result in a larger blocking effect. Blocking scores were collected for both stress and safety conditions and these were used to determine how learning occurred in each condition. Taking the difference of these scores allowed us to see how impactful the stress condition was on learning and what kind of effect it created on learning about positive and negative outcomes. That is, the primary aim of this study was to evaluate how stress affects learning about positive and negative outcomes using a blocking design. As previous literature found inconsistent results, we could not formulate a clear hypothesis regarding whether stress will either enhance or disrupt learning.

The other aim of this study was to determine whether anxiety could predict the blocking scores under stress and safety. This was investigated to determine if highly anxious individuals performed differently in conditions of stress (relative to safe conditions). Anxiety has been closely linked with stress in the literature (Anisman & Matheson, 2005) and it is worth investigating the impact anxiety may have when learning under stress.

Our aim was to test whether stress has a larger impact on blocking scores for highly anxious individuals when compared to non-anxious individuals. We expected higher anxiety to be associated with a larger difference in learning under stress relative to safe conditions.

4.1 Aim 1 & 2: Learning about Positive & Negative Outcomes under Stress vs. Safety

Our first aim was to investigate whether the blocking scores for positive outcomes (happy faces) differ between the stress and safety conditions. This would indicate that stress impacts learning about positive outcomes.

For positive outcomes (Aim 1) the stress condition did create differences in learning about the cues and resulted in differences in blocking scores. This confirms that when an individual is under stress they learn differently and there is an impact when the outcomes are positive.

Significant blocking was found for the stress condition for positive outcomes, meaning that learning about the control stimuli was stronger than learning about the blocked stimuli. This means that learning under stress had a specific impact on learning about the blocked stimuli. Participants minimised what they learned about when they were under stress for efficiency. They streamlined their learning and only focused on important stimuli and completely ignored the blocked (redundant) stimuli.

However, in the safety condition there was no blocking effect at all. Instead the blocked stimuli were learned as well as the control stimuli. All stimuli were learned about equally, including the blocked stimuli. This could be explained by individuals feeling relaxed in the safe conditions, which perhaps allowed them to learn about all cue-outcome relationships, including redundant ones. When relaxed, they seemed to choose to focus on everything and learn about all stimuli present.

This indicates that in our study the stress manipulation seemed to result in learning that is 'streamlined' for positive outcomes. The precise learning for each stimuli may not differ dramatically across conditions (control stimuli were only slightly more learned about in the stress condition compared to safety), stress instead seemed to allow individuals to pay attention to what is most important so learning resources were more devoted toward essential stimuli. The blocked stimuli do not indicate anything new above and beyond the blocking stimuli (i.e., they do not signal a new outcome), so they are redundant and perhaps not worth learning about. Only the important things (the more predictive cues) were learned about under stress when outcomes are positive. Whereas under safe conditions, individuals may learn more about their environment because they have the capacity to do so due to no stress.

For negative outcomes (Aim 2), no significant results were found, meaning that there was no blocking effect present for either the stress or safety conditions. This appears to indicate that in our study stress had no impact on learning about negative outcomes.

Previous evidence indicates that stress does impact learning; however it is mostly dependent on various conditions such as timing, intensity, emotional content, and type (Aberg et al., 2012). It is also widely evidenced that learning and decision making are directly related to positive and negative outcomes and what we perceive the outcome to be (Lighthall et al., 2013). Therefore stress impacts decision making and learning, which in turn has an effect on whether expect an outcome to be positive or negative.

However, the evidence for how stress affects learning about positive and negative outcomes is mixed. There are studies reporting that positive outcome learning is disrupted under stress (Berghorst et al., 2013; Bogdan, Santesso, Fagerness, Perlis, & Pizzagalli, 2011; de Berker et al., 2016; Cremers, Veer, Spinhoven, Rombouts, & Roelofs, 2014), while there is also evidence for it being enhanced (Lighthall et al., 2013). The same is found for negative outcome learning: some studies found that stress disrupts learning (Petzold et al., 2010; Harrison et al., 2016) and others found evidence for enhancement (Cavanagh et al., 2011). Therefore there is a lack of consensus on how stress impacts these outcomes so it was important to focus on that in our study.

Comparing our findings to previous evidence, only one study discussed had results consistent with ours. Lighthall and colleagues (2013) tested for stress increasing reward salience, and found that their cold pressor stress manipulation enhanced learning about positive outcomes. While their study involved a different stress condition, a different way of measuring learning (reinforcement learning of simple cue-response relationships rather than a blocking design) they found results that are consistent with ours.

In comparison, multiple studies found contradictory evidence to ours, i.e., that learning about positive outcomes was disrupted while under stress. de Berker and colleagues (2016) investigated Pavlovian biases where they tested the impact of reward and punishment on actions and how stress impacted this. They found that actions failed to be produced under stress for their positive cues. Cremers and colleagues (2014) focused more on social anxiety when testing the effect of stress on learning, and were looking at social reward and motivational preference, which differs considerably from the types of learning under stress investigated here. Berghorst and colleagues (2013) measured cortisol levels when testing for stress and involved a more complicated experiment design, while Bogdan and colleagues (2011) took a more genetic approach to their findings. All these studies with contrary results conducted different experiment conditions and were measuring different types of stress, which may explain the inconsistencies between their and our results.

4.2 Aim 3: Relationship between Blocking and Anxiety

The second aim for our study was to investigate whether there is a more pronounced difference in learning (blocking scores) between conditions (stress vs. control) for anxious participants. This means that we expected stress to be more impactful on anxious participants.

Our findings show that anxiety could predict the impact of stress on blocking scores, but only for positive outcomes. This is possibly due to our non-significant results for negative outcomes (we did not find a blocking effect with negative outcomes). When comparing stress and safety conditions, the blocking effect was stronger under stress especially for anxious individuals. More specifically, anxious individuals ignored the blocked cues to a larger extent and focused their attention more closely on the control cues.

These findings indicate that highly anxious individuals have a stronger tendency to focus on a more limited number of cues that predict positive outcomes under stress. This can be due to the increased cognitive load on mental capacity that stress can have on anxious individuals. A highly stressed individual may be more focused on the anticipation of a stressor that they find it harder to learn about stimuli. When blocking is involved, this means that the blocked cue is ignored more because there is more focus on impending stressors. Learning is focused on what is essential, which in this study is the control cues. An increased focus on the stressor and anticipation of it occurring would therefore reduce learning about all cues.

This can also be explained through selective threat appraisal. When a highly anxious individual feels they are in danger they suffer from a lack of selective threat appraisal. Instead of determining what in the dangerous situation is threatening, all stimuli present are tagged as high threat and become fear eliciting stimuli (Boddez et al., 2012). If an individual is overestimating the danger of a situation, they will be unable to focus on anything else happening in the event. In the case of our experiment, the fear of hearing a loud burst of white noise was more overpowering for highly anxious individuals that it made it more difficult for them to focus on learning about blocked cues (the least informative cues in this design); as they were perhaps more focused on their stress.

Anxiety is also associated with increased perception of uncontrollability of stressors (Pizzagalli et al., 2007) which would also make it harder to perform in a learning task. Additionally, feelings of worry, apprehension, a perceived sense of unpredictability, and a lack of control towards future aversive events are all symptoms of anxiety (Grillon, 2002). These would all contribute to a greater blocking effect in learning. This suggests that it is more difficult for an individual focused on a stressor to learn about positive outcomes, so there is less learning about the least informative (blocked) cues.

Previous studies discussing anxiety and stress with learning rarely mention blocking. Boddez and colleagues (2012) did investigate the role of blocking in anxiety and found that anxiety was linked to performance in a blocking task. However, they only investigated negative outcomes and found that blocking was reduced in individuals with high anxiety. They also did not study the influence of stress. Our study demonstrated a relationship between anxiety and learning under stress using a blocking design, but it is difficult to compare our results to previous research as there are no previous studies that investigated all three topics (learning, stress, and anxiety).

4.3 Strengths

The blocking design used in our study allowed for a more robust form of testing of the effects of stress on learning from prediction errors. This study is the first to use a blocking design to study the effects of stress on learning. Previous studies used simpler learning tasks in which individual cues were associated with an outcome so participants learned only simple cue-outcome relationships (e.g., A → Happy, B → Fearful). Using a blocking design (A → Happy, AB → Happy, CD → Happy), allows us to better test the prediction error theory according to which learning about B, the blocked stimulus, should be reduced as a result of reduced prediction error relative to the control cues C and D.

The happy and fearful faces chosen as outcome variables were successful as simple positive and negative outcome generators. By using these faces it made it easy to create a specified outcome in a laboratory setting. Participants presumably experienced positive and negative feelings, as happy and fearful faces have been shown to elicit different amygdala responses (Robinson et al., 2013), without needing an elaborate design to create a situation that would evoke those feelings.

The images used as cues were adequately generalised for all participants. By using images that had no previous associations with the outcomes we were able to guarantee that all participants were experiencing the cues in the same way and creating associations for them through the experiment and not by previous experience. Other studies used cues such as Japanese hiragana symbols which could be a confounding variable for participants who understood Japanese.

Furthermore, the current study featured three anxiety measures. This allowed for versatility and adaptability if any issues arose for participants for any of the measures. Having three measures allowed for more robust scoring of anxiety since we were able to combine all measures into one score rather than just using a single measure to estimate levels of anxiety.

4.4 Limitations and Future Directions

One of the main limitations of this study is the sample is not representative of a general population. We recruited from a first year psychology student pool where students participated in return for class credit. So the results of this study are only representative of first year psychology students and not of the general population. The sample consisted of 81.82% of participants in the 18-25 age group and primarily females (63.64%). Our sample is also relatively small with only twenty-two participants. Therefore, the results of the correlational analysis should be interpreted with caution due to the small sample size.

Another limitation of this study is the impact of running both the stress and safety conditions in a within-subjects design. Our safety condition had non-significant results and no blocking effect. It can be argued that the stress condition may have had a bleed over effect into our safety condition where participants were still affected by the white noise burst even when they knew they were not at risk. If these conditions had been tested in separate sessions, our results may have been very different. Additionally, when compared to other stress studies, our stress manipulation was quite mild. The use of a burst of white noise might not have been an effective enough stressor for all participants. This could have had an impact when considering the inverted u-shape theory that argues that stress only affects learning at certain levels of intensity. This might explain why the white noise stress manipulation was ineffective in the negative outcome condition.

Further study needs to focus on using blocking to test the effects of stress on learning. The results here indicate that only blocking for positive outcomes was enhanced, and future studies could attempt to replicate this effect. This also applies to anxiety studies; there needs to be more studies focusing on blocking with anxiety to investigate this relationship further. There are too many gaps in the literature and blocking is often ignored. Learning about positive outcomes in particular tends to be ignored, as most studies that investigated anxiety and blocking only used negative outcomes.

Future studies could adapt the design used here and try running the stress and safety conditions separately. This could have more impactful results and provide more insight into the role stress plays in blocking and learning. Additionally, testing the intensity of stressors is an area that could be further investigated. A study that used a stressor at a different intensity in each condition and compared the effect of each stressor's intensity on the blocking effect could provide more understanding into the inverted u-shape theory and the impact stress has on learning.

4.5 Conclusions

The present study demonstrated that stress has an impact on learning about positive outcomes. It presents a meaningful insight into the effects of stress by using a blocking design to determine whether prediction error processing is affected by stress relative to safety conditions. Findings suggest that blocking is stronger when a stressor is present while learning about positive outcomes. This study represents a strong paradigm to investigate the effects of stress on learning and paves the way for future studies to investigate this relationship in more depth and allow a stronger understanding of how positive and negative outcomes are learned about in different conditions.

This study has also demonstrated insight into the relationship between anxiety and the effects of stress on learning. Anxiety was associated with the strength of the stress effect on blocking with positive outcomes. The present study provides a base for future investigation into anxiety and blocking, and the modulation of this effect by stress.

These are important areas to research due to how integrated stress is in everyday life. Every person experiences stress and it is ingrained into decision making. Having a deeper understanding on how stress impacts us when we learn is important, especially at a university level where stress learning is incredibly common. Anxiety is closely related to stress processes and understanding how these tie together and affect each other when it comes to learning is also vital to study.

References

Aberg, K. C., Clarke, A. M., Sandi, C., & Herzog, M. H. (2012). Trait anxiety and post-learning stress do not affect perceptual learning. *Neurobiol Learn Mem, 98*(3), 246-253. doi:10.1016/j.nlm.2012.08.006

Anisman, H., & Matheson, K. (2005). Stress, depression, and anhedonia: caveats concerning animal models. *Neurosci Biobehav Rev, 29*(4-5), 525-546. doi:10.1016/j.neubiorev.2005.03.007

Arnaudova, I., Krypotos, A. M., Effting, M., Boddez, Y., Kindt, M., & Beckers, T. (2013). Individual Differences in Discriminatory Fear Learning under Conditions of Ambiguity: A Vulnerability Factor for Anxiety Disorders? *Front Psychol, 4*, 298. doi:10.3389/fpsyg.2013.00298

Bados, A., Gomez-Benito, J., & Balaguer, G. (2010). The state-trait anxiety inventory, trait version: does it really measure anxiety? *J Pers Assess, 92*(6), 560-567. doi:10.1080/00223891.2010.513295

Berghorst, L. H., Bogdan, R., Frank, M. J., & Pizzagalli, D. A. (2013). Acute stress selectively reduces reward sensitivity. *Front Hum Neurosci, 7*, 133. doi:10.3389/fnhum.2013.00133

Boddez, Y., Haesen, K., Baeyens, F., & Beckers, T. (2014). Selectivity in associative learning: a cognitive stage framework for blocking and cue competition phenomena. *Front Psychol, 5*, 1305. doi:10.3389/fpsyg.2014.01305

Boddez, Y., Vervliet, B., Baeyens, F., Lauwers, S., Hermans, D., & Beckers, T. (2012). Expectancy bias in a selective conditioning procedure: trait anxiety increases the threat value of a blocked stimulus. *J Behav Ther Exp Psychiatry, 43*(2), 832-837. doi:10.1016/j.jbtep.2011.11.005

Bogdan, R., Santesso, D. L., Fagerness, J., Perlis, R. H., & Pizzagalli, D. A. (2011). Corticotropin-releasing hormone receptor type 1 (CRHR1) genetic variation and stress interact to influence reward learning. *J Neurosci, 31*(37), 13246-13254. doi:10.1523/JNEUROSCI.2661-11.2011

Campos, A. C., Fogaca, M. V., Aguiar, D. C., & Guimaraes, F. S. (2013). Animal models of anxiety disorders and stress. *Rev Bras Psiquiatr, 35 Suppl 2*, S101-111. doi:10.1590/1516-4446-2013-1139

Cavanagh, J. F., Frank, M. J., & Allen, J. J. (2011). Social stress reactivity alters reward and punishment learning. *Soc Cogn Affect Neurosci, 6*(3), 311-320. doi:10.1093/scan/nsq041

Cremers, H. R., Veer, I. M., Spinhoven, P., Rombouts, S. A., & Roelofs, K. (2014). Neural sensitivity to social reward and punishment anticipation in social anxiety disorder. *Front Behav Neurosci, 8*, 439. doi:10.3389/fnbeh.2014.00439

de Berker, A. O., Tirole, M., Rutledge, R. B., Cross, G. F., Dolan, R. J., & Bestmann, S. (2016). Acute stress selectively impairs learning to act. *Sci Rep, 6*, 29816. doi:10.1038/srep29816

Grillon, C. (2002). Associative learning deficits increase symptoms of anxiety in humans. *Biol Psychiatry, 51*(11), 851-858.

Harrison, N. A., Voon, V., Cercignani, M., Cooper, E. A., Pessiglione, M., & Critchley, H. D. (2016). A Neurocomputational Account of How Inflammation Enhances Sensitivity to Punishments Versus Rewards. *Biological Psychiatry, 80*, 73-81. doi:10.1016/j.biopsych.2015.07.018

Joels, M., Pu, Z., Wiegert, O., Oitzl, M. S., & Krugers, H. J. (2006). Learning under stress: how does it work? *Trends Cogn Sci, 10*(4), 152-158. doi:10.1016/j.tics.2006.02.002

Kamin, L. J. (1969). Predictability, Surprise, Attention, and Conditioning. In B. A. C. Campbell, R. M. (Ed.), *Punishment and Aversive Behavior* (pp. 279-298). New York: Appleton-Century-Crofts.

Lighthall, N. R., Gorlick, M. A., Schoeke, A., Frank, M. J., & Mather, M. (2013). Stress modulates reinforcement learning in younger and older adults. *Psychol Aging, 28*(1), 35-46. doi:10.1037/a0029823

Lovibond, P. F., & Lovibond, S. H. (1995). The structure of negative emotional states: comparison of the Depression Anxiety Stress Scales (DASS) with the Beck Depression and Anxiety Inventories. *Behav Res Ther, 33*(3), 335-343.

Lovibond, S. H., & Lovibond, P. F. (1993). *Manual for the Depression Anxiety Stress Scales (DASS)*: Psychology Foundation Monograph.

MacLeod, C., Rutherford, E., Campbell, L., Ebsworthy, G., & Holker, L. (2002). Selective attention and emotional vulnerability: assessing the causal basis of their association through the experimental manipulation of attentional bias. *J Abnorm Psychol, 111*(1), 107-123.

Navarro-Frances, C. I., & Arenas, M. C. (2014). Influence of trait anxiety on the effects of acute stress on learning and retention of the passive avoidance task in male and female mice. *Behav Processes, 105*, 6-14. doi:10.1016/j.beproc.2014.02.009

Ness, D., & Calabrese, P. (2016). Stress Effects on Multiple Memory System Interactions. *Neural Plast, 2016*, 4932128. doi:10.1155/2016/4932128

Oei, T. P., Sawang, S., Goh, Y. W., & Mukhtar, F. (2013). Using the Depression Anxiety Stress Scale 21 (DASS-21) across cultures. *Int J Psychol, 48*(6), 1018-1029. doi:10.1080/00207594.2012.755535

Olszanowski, M., Pochwatko, G., Kuklinski, K., Scibor-Rylski, M., Lewinski, P., & Ohme, R. K. (2014). Warsaw set of emotional facial expression pictures: a validation study of facial display photographs. *Front Psychol, 5*, 1516. doi:10.3389/fpsyg.2014.01516

Page, A. C., Hooke, G. R., & Morrison, D. L. (2007). Psychometric properties of the Depression Anxiety Stress Scales (DASS) in depressed clinical samples. *Br J Clin Psychol, 46*(Pt 3), 283-297. doi:10.1348/014466506X158996

Petzold, A., Plessow, F., Goschke, T., & Kirschbaum, C. (2010). Stress reduces use of negative feedback in a feedback-based learning task. *Behav Neurosci, 124*(2), 248-255. doi:10.1037/a0018930

Pizzagalli, D. A., Bogdan, R., Ratner, K. G., & Jahn, A. L. (2007). Increased perceived stress is associated with blunted hedonic capacity: potential implications for depression research. *Behav Res Ther, 45*(11), 2742-2753. doi:10.1016/j.brat.2007.07.013

Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. P. Black, W. R. (Ed.), *Classical Conditioning II* (pp. 64-99). New York: Academic Press.

Robinson, O. J., Overstreet, C., Charney, D. R., Vytal, K., & Grillon, C. (2013). Stress increases aversive prediction error signal in the ventral striatum. *Proc Natl Acad Sci U S A, 110*(10), 4129-4133. doi:10.1073/pnas.1213923110

Salehi, B., Cordero, M. I., & Sandi, C. (2010). Learning under stress: the inverted-U-shape function revisited. *Learn Mem, 17*(10), 522-530. doi:10.1101/lm.1914110

Shackman, A. J., Sarinopoulos, I., Maxwell, J. S., Pizzagalli, D. A., Lavric, A., & Davidson, R. J. (2006). Anxiety selectively disrupts visuospatial working memory. *Emotion, 6*(1), 40-61. doi:10.1037/1528-3542.6.1.40

Spielberger, C. D., Gorsuch, R. L., & Lushene, R. E. (1970). *STAI: Manual for the State-Trait Anxiety Inventory*. Palo Alto: Consulting Psychologists Press.

Spielberger, C. D., & Vagg, P. R. (1984). Psychometric properties of the STAI: a reply to Ramanaiah, Franzen, and Schill. *J Pers Assess, 48*(1), 95-97. doi:10.1207/s15327752jpa4801_16

Starcke, K., & Brand, M. (2016). Effects of stress on decisions under uncertainty: A meta-analysis. *Psychol Bull, 142*(9), 909-933. doi:10.1037/bul0000060

Terao, K., Matsumoto, Y., & Mizunami, M. (2015). Critical evidence for the prediction error theory in associative learning. *Sci Rep, 5*, 8929. doi:10.1038/srep08929

Tobler, P. N., O'Doherty J, P., Dolan, R. J., & Schultz, W. (2006). Human neural learning depends on reward prediction errors in the blocking paradigm. *J Neurophysiol, 95*(1), 301-310. doi:10.1152/jn.00762.2005

Torrence, R. D., & Troup, L. J. (2018). Event-related potentials of attentional bias toward faces in the dot-probe task: A systematic review. *Psychophysiology, 55*(6), e13051. doi:10.1111/psyp.13051

Treadway, M. T., Admon, R., Arulpragasam, A. R., Mehta, M., Douglas, S., Vitaliano, G., . . . Pizzagalli, D. A. (2017). Association Between Interleukin-6 and Striatal Prediction-Error Signals Following Acute Stress in Healthy Female Participants. *Biol Psychiatry, 82*(8), 570-577. doi:10.1016/j.biopsych.2017.02.1183

Vagg, P. R., & Spielberger, C. D. (1980). Is the State-Trait Anxiety Inventory Multidimensional? *Personality and Individual Differences, 1*, 207-214.

Yerkes, R. M., & Dodson, J. D. (1908). The Relation of Strength of Stimulus to Rapidity of Habit-Formation. *Journal of Comparative Neurological Psychology, 18*, 459-482.

Appendix A: Information Sheet

THE UNIVERSITY of ADELAIDE

SCHOOL OF PSYCHOLOGY
FACULTY OF HEALTH SCIENCES

THE UNIVERSITY OF ADELAIDE
SA 5005
AUSTRALIA

Information Sheet

Study Title
Learning under stress

Investigators
Alex Pamment
Dr Irina Baetu

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 two computerised tasks in which they learn whether various pictures frequently occur together. Each task will be divided into several blocks. In some of the blocks participants will be at risk of hearing bursts of loud noise while they learn, whereas in other blocks they will be safe, as the loud noise will not be played during these blocks. **The bursts of loud noise are aversive given their intensity, 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. To assess their mood, participants are asked to complete several mood questionnaires.

Location
The study takes place in the Hughes building room 241, 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 H-17/14). 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:	[redacted]

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 co-ordinator:

Name:	**Dr Irina Baetu**
Phone:	[redacted]
Name:	**Professor Nick Burns**
Phone:	[redacted]

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 B: Consent Form

THE UNIVERSITY of ADELAIDE

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

Investigators
Alex Pamment
Dr Irina Baetu

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: …………………..………………...