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EXAMINING WORKING MEMORY, TRAIT ANXIETY AND COMPLEX DECISION MAKING IN UNIVERSITY
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Examining the Relationship between Working Memory, Trait Anxiety and Complex Decision Making
in University Students

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Abstract

The current research aims to contribute to the literature by examining the previously untested relationship of individual differences in working memory, trait anxiety and Iowa gambling task performance in healthy adults. Previous research has found working memory negatively relates to trait anxiety, and that trait anxiety has been positively and negatively related to Iowa gambling task performance, yet working memory and Iowa gambling task performance are often positively related to one another. In order to explore this uncertain relationship the current experiment hypothesised that trait anxiety and working memory would correlate with Iowa gambling task performance, and would combine to explain additional variance of Iowa gambling task performance. Two complex span measures of working memory were used to examine general domain working memory; operation span and symmetry span. Anxiety was measured using the trait component of the state-trait anxiety inventory. 64 students $M=20.69$, $SD=2.57$ completed each measure in the current experiment. A multiple regression analysis was used to examine the correlation between measures of working memory, anxiety, and complex decision making, the experiment found no relationship between any of the variables. The results are discussed in relation to the attentional control theory, the somatic marker hypothesis, the fuzzy trace theory, and tripartite theory. It concludes by arguing that working memory and trait anxiety are related to Iowa gambling task performance but in a nonlinear way, and postulating the need for more comprehensive research that reflects the multifaceted demands of Iowa gambling task performance.

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Individual Differences in Working Memory, Trait Anxiety and Complex Decision Making in University Students

Introduction

Anxiety is a heightened state of arousal that can occur when perceiving threatening stimuli, it is often characterised by increased tension, apprehension, nervousness, worry and activation of the autonomic nervous system which mobilises metabolic resources in order to meet the expected environmental demands (Lang, Bradley, & Cuthbert, 1990). From an evolutionary perspective a state of anxiety is adaptive as it increases sensory perception, physical reaction speed, strength and other factors that increase the chance of escaping or fighting threats to survival or reproduction (Porges, 1997). Trait anxiety is differentiated from state anxiety and defined as a stable tendency or personality disposition towards perceiving stimuli as threatening or dangerous, and a propensity to experience more intense states of anxiety more frequently (Spielberger 1970; Spielberger & Sydeman 1994).

High levels of trait anxiety has been shown to be an indicator of common affective disorders, for example general anxiety and major depression as measured by both questionnaires and clinical interview has been found to relate to high trait anxiety (Kennedy, Schwab, Morris & Beldia, 2001), additionally the occurrence of PTSD after a stressful encounter can be predicted by previously measured trait anxiety (Weems et al., 2007). The prevalence of anxiety and depression worldwide has remained stable over the last 20 years at 4% for anxiety and at 4.4% for major depression (Baxter et al., 2014). Anxiety is disproportionately prevalent in women (Kessler & Bromet, 2013), and

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unsurprisingly in the most vulnerable members of society such as young, physically disabled, people with lower socioeconomic status, lower education, and those with a coexisting mental illness (Kessler & Bromet, 2013; McLaughlin et al., 2010; Remes, Brayne, van der Linde, & Lafortune, 2016). Affective disorders are some of the largest burdens on society with anxiety disorders accounting for 3.5% of years of employment lost due to disability; making it the sixth largest cause of years lived with a disability worldwide (Baxter, Vos, Scott, Ferrari, & Whiteford, 2014), whereas major depression disorder accounted for 8.2% of years; making it globally the second most prevalent disability by years endured (Ferrari et al., 2013). Having an affective disorder is a risk factor for a number of negative health outcomes such as cardiovascular disease (Vogelzangs et al., 2010), poor dietary habits, low levels of exercise (Lopresti, Hood, & Drummond, 2013), poor medical treatment adherence (DiMatteo, Lepper, & Croghan, 2000), drug and other addictions (Grant et al., 2004; Akin & Iskender, 2011), obesity (Rofey et al., 2009), and suicide (Fergusson, Woodward, & Horwood, 2000). Treatments for affective disorders such as psychotherapy and medication often have low retention rates (Fernandez, Salem, Swift & Ramtahal, 2015) and when improvement occurs treatments often suffer from low long term effectiveness (Adler Nevo et al., 2014). Several studies report emotional wellbeing, depression and anxiety are highly related to secure social relationships (Eng, Heimberg, Hart, Schneier & Liebowitz, 2001), financial success and poverty (Falconnier, 2009), eating habits (Jacka, Mykletun, Berk, Bjelland & Tell, 2011), exercise frequency (Ströhle, 2008), and addictive behaviours (Grant et al., 2004; Akin & Iskender, 2011; Leventhal & Zvolensky, 2015). These behaviours have also been associated with lower working memory capacity (de Wilde, Koot, & van Lier, 2015; Evans & Schamberg, 2009; Jefferson et al., 2011) and what has been referred to as complex (Gupta et al., 2009), affective (Torrvalva et al., 2007), ambiguous (Zhang, Wang, Zhu, Yu, & Chen, 2015), and

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intuitive decision making (Payne 2008). Understanding how differences in intelligence and decision making relate to anxiety justifies examination, therefore the current thesis aims to examine the relationship between working memory and complex decision making

One way to improve treatment and prevention of anxiety is to understand the cognitive factors that underlie the mental illness, and use this understanding in novel treatments or in identification. It is well established that differences in working memory capacity negatively relate to trait anxiety (Moran, 2016), and research has also found that working memory positively correlates with treatment effectiveness of affective disorders (Mohlman & Gorman, 2005). Moreover training working memory can reduce trait anxiety (Sari, Koster, Pourtois & Derakshan, 2016), and training emotion related working memory has been related to greater improvements (Schweizer, Hampshire & Dalgleish, 2011). Trait anxiety has also been unreliably related to complex decision making with evidence of a positive, negative, non-linear relationship, and no relationship (e.g. Rocha, Alvarenga, Malloy-Diniz, & Corrêa, 2011; Werner, Duschek, & Schandry 2009; Zhang, Wang, Zhu, Yu, & Chen 2015). Finally there is also relatively weak evidence that individual differences in working memory positively relates to complex decision making (Toplak, Sorge, Benoit, West, & Stanovich, 2010; Bagneux, Thomassin, Gonthier & Roulin 2013). If working memory does not positively relate to complex decision making then this would conflict with prominent dual process theories that are influential in the clinical treatment of anxiety (Barber & DeRubeis, 1989; Evans & Stanovich, 2013; Stanovich & West, 2000), these theories argue the integration and short term retention of complex information is considered to be the result of slow and effortful processes that necessarily require working memory. Therefore the relationship between trait anxiety, working memory, and emotional decision making capacity should be explored to enhance understanding of behaviour in those

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predisposed towards affective disorders, in order to facilitate treatment and prevention by highlighting what support is necessary in people with high trait anxiety.

Another reason to study how working memory and complex decision making that relate to anxiety is that it furthers the understanding of how people make decisions in everyday life, which is a fundamental question for the study of psychology and behavioural sciences. That is to say that the extent to which emotions influence complex decision making or whether decisions are impaired by limited working memory capacity is of theoretical importance. This thesis considers on the dichotomy of the rational conscious mind and unconscious emotional reactions accepted by the prominent dual process theories, insofar as it briefly examines the extent to which conscious deliberation is the basis for effective complex decisions. Descartes (Herrnstein 1965) argued that the mind existed inside the body and was responsible for certain aspects of the person such as intelligence, but conscious awareness or the soul exists outside the physical being, and interacts with the body through the pineal gland. Modern arguments for dualism are widely believed and encouraged by academic theories of psychology. Like Descartes they argue for a specific region responsible for consciousness within the brain; and these processes govern other regions of the brain which are considered automatic reflexive responses (Gyurak, Gross & Etkin, 2011). Some theories argue that causation resides in the region responsible for working memory; the dorsal lateral prefrontal cortex (dlPFC), which allows for active deliberation referred to as consciousness (Gyurak, Gross & Etkin, 2011), 'will', and even a 'homunculus' (Baddeley, 2002).

Dual process accounts argues for a competitive relationship between type one, so called 'lower' emotional processes, and type two, so called 'higher' rational systems (Evans & Stanovich, 2013; Janis & Mann, 1977; Mann, 1992). Type one processes are employed for the majority of behaviours and

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consists of previously associated responses; described as 'autonomous', predefined, and 'automatic', . Type two processing is described as higher cognitive processing (Barrett, Tugade, & Engle, 2004; Evans & Stanovich, 2013) which intervenes and inhibits automatic responses under certain conditions, this is described as occurring due to several factors. While there is a disagreement amongst theorists, a 'meta cognitive feeling of rightness' is often argued to determine or instigate top down cognitive control (Evans & Stanovich, 2013). Higher cognition controls reflexive emotional responses in order to advance goal orientated behaviour, higher processes are limited, and affect can greatly influence or override the cognitive elements of decision making (Loewenstein, & Lerner, 2003). This includes instances where emotional reactions towards the decisions incurs an affective state that is able to influence or overcome cognitive deliberation, for example when a person knows that flying is statistically safer than driving but chooses to drive rather than fly because of a flying phobia. The dual process model argues that there are two distinct representations of a concept; one cognitive and one emotional, which compete to dictate behaviour. While some theories also argue that emotions can have a varied impact on decision making (Janis & Mann, 1977; Mann, 1992), dualist tradition regards complex decision making to be the result of top-down executive processes which simulate hypothetical outcomes by combining cognitive representations (Evans & Stanovich, 2013). As such, emotion reduces the effectiveness of the rational choice by biasing the response, or through distraction that require attentional resources to refocus.

Contradicting positions suggest emotion is responsible for reasoning, David Hume (1778, p. 415) argued "reason is... the slave of the passions, and can never pretend to any other office than to serve and obey them". Similarly a theory championed by Damasio (1994, 1996, 2004) the somatic marker hypothesis (somatic marker hypothesis) contends that emotion is central to any decision as any value

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ascribed to an option is intrinsically emotional. Damasio describes all decisions as a comparison of simulations from previously experienced stimuli which elicit similar but weaker somatic responses. This is in contrast to traditional dual process accounts of economic decision making that argue decisions are the product of cognitive cost-benefit analysis, while emotions were primarily considered in terms of interpreting the consequences of behaviour (Janis and Mann, 1977; Mann, 1992, cited in Bechara & Damasio 2005). Additionally the theory argues that conscious thought is unnecessary for certain instances of rational complex decision making, it posits that emotional processes are capable of integrating associated stimuli and comparing them with alternatives; this process is referred to as valuation. The theory primarily uses neurological evidence in order to demonstrate a new perspective within the debate and there have been some aspects of how cognitive and emotional elements relate to complex decision making.

This thesis aims to fill a gap in the research regarding the extent decision making performance is related to trait anxiety and working memory, in theoretical terms it aims to examine how differences in experiencing decision outcomes reflected by trait anxiety, and differences in working memory influences complex decision making performance.

Trait Anxiety

The relationship between anxiety and cognitive performance has been considered for over a century. The Yerkes-Dodson law (Yerkes & Dodson, 1908) posits that arousal influences performance in a curvilinear manner, that is performance is worst at extreme high and extreme low levels of arousal and peaks at a moderate level. Although this relationship appears consistent critics have argued that

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the theory lacks an explanation of internal events (Eysenck, 1985; Landers, 1980), and was too simplistic because it did not account for task difficulty and other factors (Edwards 2015). As such, a number of theories involving anxiety and motivation have been put forward to explain the relationship between arousal and performance (Teigen, 1994). As mentioned previously trait anxiety is described as a predisposition towards states of anxiety (Bishop 2007) which is characterised by activation of the autonomic nervous system. Recent theory has stressed the importance of worrying thoughts when considering cognitive impairments related to high levels of trait anxiety (Balsamo et al., 2013, Kazdin, 2000). Thus contemporary therapy focuses on reducing maladaptive thoughts when treating anxiety (Barber & DeRubeis, 1989), these thoughts are considered as a failure to inhibit and redirect attention in accordance with dual process theories.

Theories of how anxiety is related to cognitive performance

Attentional Interference Theory (Sarason, 1984) argues that anxiety primarily influences executive function through increasing the number of worry related thoughts. These are described as task irrelevant thoughts that divide available cognitive resources. Although this theory gained support (Sarason, Sarason, Keefe, Hayes, & Shearin, 1986) it was criticised because it lacked an explanation for instances where anxiety improved performance (Eysenck & Calvo, 1992). Personality, motivation and performance theory (Humphreys & Revelle 1984) attempted to explain this phenomena. It argues motivation determines the nature of executive function through different ways of allocating cognitive resources, determining if a task is performed quickly and inaccurately or slowly and accurately. Anxiety increases motivation to attend to both task relevant and task irrelevant stimuli which limits working memory capacity by consuming cognitive resources. Consequently this theory explains

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evidence that anxiety can increase performance in simple tasks as increased effort and explains impaired performance during complex tasks as impaired working memory availability.

Attentional control theory (Eysenck et al., 2007) expands upon the personality motivation and performance theory and argues that anxiety impairs cognitive efficiency rather than performance per se, the attentional control theory argues that cognitive impairments caused by anxiety are often underreported due to an increase in effort that is associated with anxiety. It posits that anxiety is related to increased effort when demands on working memory are low, but that cognitive performance is lower when demands are high compared to non-anxious individuals (Eysenck & Calvo, 1992). The theory refers to this as a difference in efficiency rather than a direct impairment to performance as proposed by previous models (Sarason, 1984). The attentional control theory argues that this difference in efficiency causes an increase in the type one, stimulus driven attention processes but reduces the available resources of the type two attention or central executive. Moreover worrying thoughts prompt an increase in effort in order to mitigate the impairment. This reduces efficiency but also increases performance under moderate load (Eysenck & Derakshan 2011). The attentional control theory (Eysenck et al, 2007) argues that impairments to executive functions cause both cognitive processing inefficiency due to worry related thought, which require attention to be redirected. The theory argues that working memory requires 'inhibition' of previously acquired responses that are no longer reinforced (Dillon & Pizzagalli, 2007), for example worrying thoughts need to be inhibited in order to stop rumination. It also argues it is necessary to shift attention between tasks or 'mental sets' by discriminating changes in behavioural requirements and responding appropriately, such as shifting from maladaptive rumination towards a goal directed activity (Bissonette, Powell, & Roesch, 2013). The attentional control theory subscribes to the position that

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inhibition and mental set shifting are components of executive function according to the multiple component model (Baddeley, 2002). Thus the extra application of executive function that occurs in order to inhibit worrying thoughts reduces efficiency by increasing load on executive function (Eysenck & Derakshan 2011). It could be argued that the attentional control theory improved upon the Personality, motivation and performance theory (Humphreys & Revelle, 1984) in regards to explaining the effect of anxiety on cognitive performance by providing specific facets of cognition which are impaired by anxiety. Research has been found to support these additional explanations; self-reported effort has been found to increase during anxiety but executive function was found to decrease (Derakshan & Eysenck, 2009; Roca & Williams, 2016) however this decrease in efficiency was associated with an increase in stimulus driven 'low' level cognition. This supports the notion that additional effort is used to mitigate the impact of anxiety and that during anxiety a greater weight is given to stimuli driven 'lower' cognition.

Evidence of cognitive impairments in trait anxiety

The relationship between cognitive impairments and anxiety as argued by the attentional control theory has accumulated support in the literature. Set shifting and inhibition efficacy have been found to negatively relate to levels of anxiety and this effect is greater during higher levels of cognitive load (Ansari, & Derakshan 2010; Ansari, & Derakshan 2011; Berggren, Richards, Taylor, & Derakshan, 2013; Edwards, Edwards, & Lyvers, 2015; Eysenck et al, 2007; Eysenck & Derakshan, 2011). Moreover working memory has somewhat consistently been found to negatively relate to anxiety (Moran 2016).

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Central to the attentional control theories' explanation of trait anxiety is that anxious thoughts impair executive function, which in turn results in a greater number of anxious thoughts (Eysenck et al., 2007). Frequent states of anxiety have been related to more negative thought biases (Van Bockstaele et al., 2014; MacLeod, Mathews & Tata, 1986; Mogg & Bradley, 2005), it is argued that these biases are the result of fear related memories (Sandi & Richter-Levin, 2009). There is evidence that experiencing anxiety increases stimuli driven attention; during state anxiety attention is biased towards emotionally related stimuli which reduces the memorability of emotionally neutral stimuli (Strange 2003). This indicates greater use of type one processing and reduced type two processing. . Neural imaging studies examining states of anxiety show that during states of anxiety regions that are responsible for fear have a greater connectivity activity with regions risible for memory and executive function.

The amygdala is responsible for motivation and emotions such as fear, during states of anxiety the amygdala shows increased interaction related activity with the hippocampus (Phelps 2004); which is responsible for memory storage (Eichenbaum, 2017). The prefrontal cortex is responsible for executive attention (Asplund, Todd, Snyder & Marois, 2010) also shows increased interaction related activity with the amygdala (Groenewegen & Uylings 2000). This suggests anxiety correlates with greater stimulus driven attention and reduced goal directed or executive function driven attention which is in accordance with the attentional control theory (Derakshan & Eysenck, 2009). Evidence has been found that suggests anxiety impairs executive function though structural differences within the brain in areas responsible for higher cognitive processes. Correlational evidence indicates greater stress is related to reduced cognitive function (Schoofs, Preuß & Wolf, 2008) and chronic exposure to states of anxiety has been shown to cause maladaptive neurological adaptations , which is to say

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changes to the brain in response to environmental stimuli, in areas responsible for higher cognitive functions in rats (McEwen, Eiland, Hunter, & Miller, 2012; McEwen & Morrison, 2013). It has been reported using MRI scanning that general anxiety disorder patients have reduced neural mass in regions that are responsible for higher cognitive processing (Schienle, Ebner, & Schäfer, 2011). This indicates that in addition to short term cognitive impairments caused by the state of anxiety, frequent exposure to anxiety can cause negative trait differences in executive function capacity.

In summary the evidence supports the attentional control theory that anxiety increases attention towards stimuli, and chronic exposure to negative affect reduces the capacity to inhibit attention directed at task unrelated stimuli. It is argued that these cognitive impairments lead to greater effort being used on ineffective coping methods during stressful events (Schoofs, Preuß & Wolf, 2008).

Working memory

The attentional control theory makes a number of assumptions regarding the nature of working memory that are relevant to the current research and must be considered. The attentional control theory assumes that there is a short term, limited capacity working memory which is depleted by worrying thoughts during states of anxiety (Eysenck et al., 2007). Specifically the attentional control theory ascribes to the multiple component model (Baddeley, 2012; Baddeley & Logie, 1999) which argues that working memory is the manipulation of information by executive attention, and that different types of sensory information are maintained in separate storage spaces. The following section describes the specific mechanisms thought to underlie working memory and discusses the evidence that is used to support this theory.

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Describing working memory.

Working memory was first conceptualised as the capacity for executive function to interact with items in short term memory, it is typically described as the ability to simultaneously manipulate, store, and maintain information (Baddeley, 2012). The involvement of working memory is described as an essential difference between type one and type two processes by influential dual process theories (Evans & Stanovich, 2013). The multiple component model argues that memory is divided by the type of sensory information that it encodes. These systems were described as the visuospatial sketchpad; responsible for stimuli relating to visual and spatial information, and the phonological loop; responsible for auditory and verbal information. Whereas type two processing is described as the central executive (Evans & Stanovich, 2013) and is responsible for cognitive manipulation, since conception the model has since added episodic buffer; which is described as a component of executive control that integrates information from multiple sensory and mnemonic sources and retrieves it into conscious awareness to permit manipulation (Baddeley, 2012).

The function of working memory.

The executive component of working memory is responsible for what dual process theories call cognitive flexibility, influential theories argue this involves separating contextual relationships or 'decoupling' a concept from contextual relationships (Stanovich & Stanovich 2010). Decoupling allows for hypothetical thinking by generating abstract concepts that are distinct from a 'real world' context. For example, perspective taking requires discriminating between what happened; the context, and what the person saw; an abstract representation of the events (Leslie, 1987). As such executive function is believed to be responsible for the capacity to understand someone else's opinion, making

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it essential for social relationships (Putko, 2009). Short term memory allows indirectly associated concepts to be associated or stored together, making them temporarily more accessible (Baddeley & Warrington, 1970). Working memory is a process which manipulates the salience and organisation of decoupled concepts that are stored in short-term memory, and the salience of the relationship between these concepts (Evans & Stanovich, 2013). The capacity to retrieve and maintain a conscious combination of decoupled representations over a prolonged period allows for the executive to control an intuitive response. For example, holding a salient visual object such as a coloured shape in working memory increases the speed of selection for less salient targets during a visual search (Dowd, Kiyonaga, Egner & Mitroff, 2015). Amongst other abilities working memory allows for multi-tasking (Hambrick, Oswald, Darowski, Rench, & Brou, 2010), hindsight bias (Calvillo, 2012), and unlearning stimulus associations (Schmidt, Houwer & Besner, 2010). Executive control often occurs in behaviour through adherence to 'explicitly endorsed attitudes' about a subject (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008). For example considering the abstract benefits of healthy eating in relation to highly salient junk food may reduce the value of the food and inhibit the intuitive response of eating it. Thus potential outcomes can be compared, this process is described as 'mentally simulating' an outcome.

Correlations between working memory and behaviour.

Much of what is deduced about working memory is gathered by comparing working memory performance with performance on other tasks, for example driving performance (Barrett, Tugade, & Engle, 2004), working memory capacity is often operationalised as performance on the complex span task. In line with the multiple component model of working memory, performance on the complex

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span tasks is argued to require cognitive flexibility in addition to short term memory (Foster et al., 2014; Redick et al., 2012). The tasks involve recalling briefly displayed target information, such as remembering a series of numbers while ignoring distracting stimuli that requires manipulation, such as completing a simple equation, (Conway et al., 2005). In order to generate a general measure of working memory without being biased by differences in domain specific short term memory capacity, a combination of tasks must be used so that each task requires manipulating stimuli associated with a different aspect of short term memory. It is unsurprising that the capacity to manipulate and maintain abstract information reportedly relates to a broad range of cognitive function, more than any other predictor working memory accounts for half the statistical variance of the capacity to reason with new information; a capacity referred to as 'general fluid intelligence' (Kane, Hambrick, & Conway, 2005). Research has found that performance on a number of cognitively demanding tasks positively relates to working memory, including the ability to pilot a plane while fatigued (Engle, 2010), reading comprehension (McVay & Kane, 2012), writing and educational activities (Vuontela et al., 2013).

Another way working memory has been identified as a form of intelligence is through its involvement in decision making. As a function of mentally simulating an outcome, working memory is argued to be responsible for delaying gratification, specifically effortful processing would be required to simulate an outcome in order to discriminate between options with abstract values and effectively respond to a multifaceted decision. It is argued by Evans and Stanovich, (2013) that working memory deficits relate to a failure to inhibit salient stimuli in favour of reflective deliberation of less salient outcomes when making a decision, a consequence of this is that long term outcomes are ignored in favour of salient short term gain when executive function is overridden by type one processing. Finn, Gunn and Gerst, (2015) examined differences in working memory and its relationship to choosing immediate

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monetary reward over delayed but more advantageous options and reported working memory is positively related to discounting delay. They argue working memory is necessary to inhibit immediately rewarding decisions by maintaining representations of future benefits, this will be discussed later in relation to complex decision making.

Finally, working memory is also implicated in tasks that are not overtly cognitive, for example working memory has been positively correlated with emotional regulation (Kleider, Parrott, & King, 2009; Schmeichel, Volokhov, & Demaree, 2008) and the ability to decode nonverbal social cues (Phillips, Tunstall, & Channon, 2007). This is in line with cognitive theories of anxiety which suggest that working memory is responsible for abstracting information and allowing cues to be associated with abstract stimuli, therefore emotion can be regulated by shifting attention from worrying task-unrelated to task related thinking back to goal orienting thinking (Evans & Stanovich, 2013).

Anxiety and Working memory

A recent meta-analysis has indicated that measures of trait anxiety are moderately negatively related to performance on working memory tasks. Over 100 experiments have examined the relationship between anxiety and performance on measures of working memory (Moran, 2016). Although the results are inconsistent the majority of studies show a negative relationship ($g = -.29$ (-.424; -1.61), $k=26$, $N=10,967$).

In particular studies indicate a high level of trait anxiety is related to lower working memory capacity (Moran, 2016) and some studies report that cognitive deficits present in high levels of anxiety are moderated by working memory (Owens, Stevenson, Hadwin & Norgate, 2012). However the

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relationship between trait anxiety and working memory is inconsistent so this section will consider in detail studies that failed to find a correlation.

It could be the case that studies that fail to find a correlation do not adequately load working memory in as according to the attentional control theory a greater impairment would be present under high working memory load for high levels of trait anxiety than low levels of trait anxiety due to differences in the amount performance is improved through effort rather than an impairment to performance on typical working memory tasks (Eysenck et al., 2007)., the attentional control theory argues high trait anxiety increases effort during tasks that involve working memory (Eysenck et al, 2007) . It could be argued some conventional measures of working memory have reported inconsistent results due to this factor. In support of the attentional control theories position, Hoshino (2015) found using a near-infrared spectroscopy that trait anxiety positively related to activation in the lateral PFC; a region associated with resisting distraction (Nee et al., 2012). Activation in this region is associated with performance on working memory tasks (Zhang, Yao, Zhang, Long & Zhao, 2013). This suggests that more cognitive resources are applied to maintain focus in patients with high trait anxiety, suggesting working memory deficits in trait anxiety are characterised by executive inefficiency. In summary high levels of trait anxiety is related to executive function inefficiency, and a more consistent relationship exists between anxiety and working memory under high load, suggesting high inter study variability could be due to differences in load across studies.

There is also evidence that this working memory impairment is The attentional control theory also posits that anxiety is related to working memory through a failure to inhibit stimuli-related task-irrelevant thoughts, which impair the capacity to control attention by incurring additional cognitive load. To test this Wright, Dobson and Sears (2014) compared the differences between levels of trait

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anxiety in complex span measure of working memory, and an antisaccade task; a task which measures the ability to inhibit saccade reflexes which is believed to indicate inhibition capacity. They found this measure of working memory performance related with trait anxiety, to predict antisaccade speed, additionally working memory performance and trait anxiety also interacted to predict unique antisaccade speed variance, although trait anxiety did not predict error rate. This supports the attentional control theory and suggests high levels of trait anxiety are related to attentional inhibition through working memory.

The relationship between clinical anxiety and working memory.

Another factor which could obfuscate the relationship between working memory and trait anxiety is the high correlation between trait anxiety and affective mental illness. Researchers who found no relationship between trait anxiety and working memory instead reported working memory performance related to different but related traits. Generalised anxiety disorder and major depression disorder (MDD) have both been found to negatively relate to working memory (Christopher & MacDonald, 2005). Castaneda et al. (2011) reported long term anxiety disorder (n=75, age; 21-35) predicted worse performance on complex span tasks compared with matched controls (n=71), although trait anxiety specifically did not correlate with working memory. Similarly Christopher and MacDonald (2005) found clinically anxious and depressed participants had impaired performance on measures of working memory compared to controls (n=88, age; 20-50), and Lyche, Jonassen, Stiles, Ulleberg and Landrø (2011) found comorbid anxiety and depression is negatively related to working memory performance (n=153). This indicates the relationship between trait anxiety and working memory may be increased or generated by the strong correlation between trait anxiety and affective mental illness (Kennedy, Schwab, Morris & Beldia, 2001), and supports the

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position that additional emotional factors interact with working memory to predict greater trait anxiety.

Another way the relationship between trait anxiety and working memory could be obfuscated is through whether a stimulus or task is interpreted as affectively laden. Studies that found no independent relationship with trait anxiety and working memory but report trait anxiety interacted with perceived stress to predict working memory (Chong 2004), and negative stimuli disproportionately engage people with anxiety disorder (Cohen et al., 2017). Many working memory tasks require the participant to remember numbers or perform calculations, maths anxiety has been shown to impair working memory performance to a greater extent on computational tasks than on letter recall tasks (Salthouse, 2012). Further variance could relate to the participant's familiarity with the stimuli which relates to greater performance (Kole, Snyder, Brojde, & Friend, 2015); for example number recall tests could disproportionately affect English literature students with high trait anxiety although this difference could be absent in letter recall. To avoid these potential confounds, multiple types of sensory stimuli should be used when testing for the relationship between anxiety and working memory. The complex span tasks involve spatial, verbal, and numeric distraction and manipulation, therefore making it an appropriate method to measure working memory capacity.

The importance of the relationship between trait anxiety and working memory has been cemented by research going beyond correlating anxiety and working memory by attempting to reduce trait anxiety through training working memory. Working memory training involves repeatedly performing tasks that require working memory in order to improve working memory, Åkerlund, Esbjörnsson, Sunnerhagen & Björkdahl (2013) found working memory training improves subclinical measures of anxiety in adults with high anxiety scores, and Hadwin and Richards (2016) found that high trait

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anxiety adolescents who undergo working memory training have greater reductions in trait anxiety and attentional control than matched controls who received typical cognitive behavioural therapy. In addition, other studies report greater improvements when working memory training involves affectively salient memory targets and distractor tasks, for example participant are required to remember the location of an angry face while recalling the order of affectively salient words (Schweizer, Grahn, Hampshire, Mobbs & Dalgleish, 2013; Schweizer, Hampshire & Dalgleish, 2011), indicating an association between working memory related emotional regulation deficits and trait anxiety. This argument is supported by fMRI evidence that the regions responsible for emotional regulation are also implicated in working memory such as the dlPFC (Buhle, et al., 2013; Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008). Together these studies provide strong evidence that working memory is related to affect through emotional regulation. Studies that fail to find a relationship between anxiety and working memory could indicate an emotional component to anxiety which protects against low working memory or mitigates the protective influence of high working memory, such as fear stimulus responsiveness (Lang & McTeague, 2009). It should be noted that this does not present a criticism of the attentional control theory, as the theory acknowledges it's limited scope, and does not account for 'implicit' (non-conscious) memory formation, which can determine trait anxiety through emotional factors (Luethi, 2008).

Summary.

This section has discussed how working memory interacts with anxiety to predict attention, how working memory capacity appears to be relatively consistently negatively related to trait anxiety (Moran, 2016), how training working memory can improve emotional regulation, and how regions

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responsible for working memory have also been implicated in emotional regulation. Potential explanations for this inconsistent relationship include the use of tasks with inadequate cognitive load or that allow strategies involving emotion, the potential overlap between affective mental illness and trait anxiety, and the possibility that differences in stimulus perception can impair high trait anxiety individuals. These results are largely concurrent with the attentional control theory although the theory is intentionally limited and does not consider many of the emotion related factors inherent to evaluating working memory experimentally, and how this may relate to real life emotional regulation. In relation to the current thesis it should be noted that the attentional control theory does not consider how anxiety can cause a greater utilisation of complex emotions, and this can have consequences for decision making tasks that require storing and manipulating complex information; conventionally considered an executive function.

Complex Decision Making

Over the past two decades a revolution in decision making research has occurred leading to a large body of research which suggests emotion is a central component in decision making (LeBlanc, McConnell & Monteiro, 2014). Recent research has reported trait anxiety (Werner, Duschek, and Schandry, 2009; Pajkossy, Dezső, & Zoltay Paprika, 2009; de Visser et al., 2010; Zhang, Wang, Zhu, Yu, & Chen, 2015), relates to complex decision making capacity positively and negatively and that working memory capacity positively relates to complex decision making (Brown et al., 2015; Bagneux, Thomassin, Gonthier, & Roulin, 2013), although the interaction between these relationships remains unknown. Prior to the shift in zeitgeist towards the involvement of emotion in decision making,

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literature was primarily focused on cognitive processes (Loewenstein, & Lerner 2003) where the decisions are determined by the perceived consequence of each option with the goal of achieving the maximum 'utility' or the expected emotional outcome. Discussion was largely limited to various biases and heuristics that simplify the decision's complexity in order to facilitate cognitive reasoning (Tversky, & Kahneman, 1975). Understanding how humans determine value is important to develop treatments that encourage choices that have positive long term consequences and reduce the negative effect of mental illnesses. From a theoretical perspective understanding value could also help elucidate the relationship between cognitive and affective processing. The following section will briefly outline the theoretical and empirical background of complex decision making.

The somatic marker hypothesis.

Distinct roles of executive function and affect in decision making were described by the somatic marker hypothesis (Damasio et al., 1991; Damasio, 1994, 1996, 2004) which argues that emotions are central to both conscious and unconscious decision making. To avoid formally defining emotion Damasio uses the term somatic markers; variations of brain and homeostatic bodily activity caused by dedicated neural regions that process a meaningful event. Meaningful events can be both internal and external from the body, the theory divides these concepts into two 'inducers'. 'Primary' inducers are stimuli that induce somatic markers which relate to positive or negative valence, whereas 'secondary' inducers are mental or internal events which are associated with primary inducers (Bechara & Damasio 2005). When making a decision the somatic marker hypothesis argues each option is related to an emotional state that is experienced during contemplation, and this experience determines the decision outcome (Damasio et al., 1991; Damasio, 1996). An example of a primary

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inducer would be the emotions and thoughts which occur when viewing a horrific car crash, an example of a secondary inducer is the memory, thoughts and arousal relating to the crash which occur when you are deciding whether to drive a car or take a train. Somatic markers also act as more subtle guidance that relate to a decision although the somatic marker itself is outside awareness, for example whether an advertisement is liked or memorable is correlated with a change in heart rate (Vecchiato et al., 2009). The somatic marker hypothesis argues this allows a complex decision to be simplified into physiological signals, which are representations of anticipated events. This allows for some options to be rejected based on their physiological associations while more favourable options can be considered more thoroughly. In addition to indicating the value of each decision, the theory argues that somatic markers signal an increase of attention and working memory (Damasio et al., 1991; Damasio, 1996) thus incorporating the central executive (Damasio et al., 1991; Damasio, 1994, 1996, 2004). This is a strength of the somatic marker hypothesis because it explains what triggers or defines when it is appropriate to allocate attentional or 'executive' resource, this process is described as the 'as-if body loop' (Bechara & Damasio, 2005). It is argued that physiologically the as-if bodily loop is argued to involve the primary region for motivation. The amygdala, interacting with changes in bodily state representations in the insular cortex. Subsequently this activates somatic states in the somatosensory cortices which are integrated into representations in the ventromedial prefrontal cortex (vmPFC). The aforementioned regions are monitored by the anterior cingulate cortex (ACC) which determines if representations are strengthened or weakened by working memory in the dlPFC (Damasio, 1994), this is relevant as much of the research supporting the somatic marker hypothesis involves neurological or physiological responses to decisions with ambiguous outcomes.

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Evidence for somatic marker hypothesis.

Studying decision making in real life poses difficulties as it is impossible to determine if a decision was made using 'reason' or if there was an emotional prompt. Therefore researchers turned to experimental tasks in order to control extraneous variables, thus the Iowa gambling task (Iowa gambling task) is often used to test the somatic marker hypothesis (e.g., Bechara & Damasio 2005; Dunn, Dalgleish, & Lawrence, 2006; Guillaume et al., 2009). In the Iowa gambling task participants are asked to make several selections from one of four decks of cards. Each deck contains a mixture of symbolic monetary rewards and losses of varying amounts and frequencies. Participants are told they are free to select decks in any order, that some decks are 'good decks' while others are 'bad decks' and they should aim to maximise overall gain. Proponents of the somatic marker hypothesis suggest that many real life decisions are too complex for reasoned argument so people often rely on their 'gut feeling'. Similarly the Iowa gambling task is allegedly too complex for cost-benefit analysis therefore participants rely on somatic based decision making.

This position has a number of assumptions which must be discussed for the purpose of this thesis

1. Somatic markers are necessary for advantageous complex decision making.

This claim was first evidenced by impairments due to vmPFC lesions which are related to emotional processing. During the Iowa gambling task patients with damage to the vmPFC failed to learn which decks are advantageous and instead chose the option with the largest reward but a greater number of losses (Bechara, Damasio, Damasio & Anderson, 1994). Importantly, control participants exhibited greater GSR and heart rate increases prior to selecting bad decks than compared to good decks (Bechara, Damasio, Tranel & Damasio, 1997) whereas vmPFC lesion patients displayed an absence of

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physiological changes in response to the bad deck. Patients with lesions to other neural areas that are implicated in emotional processing such as the amygdala and insular cortex have also displayed deficits in decision making (Bechara, Damasio, Tranel, & Damasio, 1997; Bechara, Damasio, Damasio, & Lee 1999; Bechara, Damasio, & Damasio, 2003; Clark et al., 2008). The Iowa gambling task was created to test vmPFC patients who displayed normal executive functions (Bechara, Tranel, & Damasio, 2000) but suffered from emotional impairments such as inappropriate reaction to violence, and a propensity towards making poor decisions in real life, such as risky financial investments or premature withdrawal from social relationships (Damasio et al., 1991; Bechara, Tranel, & Damasio, 2000). Patients with vmPFC lesions were described as having 'myopia for the future', or a failure to account for long term outcomes and focused on immediate consequences (Bechara et al., 1994; Bechara, 2005). It was argued vmPFC is necessary to effectively ascribe value to an object or decision based on previous experience, this ability is referred to as valuation (Hogeveen, Hauner, Chau, Krueger & Grafman, 2016). The vmPFC patients failed to generate secondary inducers because they could not create a somatic signal in relation to a deck that effectively represented losses and instead relied on primary inducers in relation to the size of the win. Thus it is argued somatic markers have a causal role in determining Iowa gambling task performance by representing experientially learned relative values.

Convincing evidence that emotions are responsible for valuation comes from neurobiological studies. Whole brain fMRI scanning has indicated that although performing the Iowa gambling task elicits activation in regions responsible for executive control, actual performance relates to greater secondary sensory cortices, vmPFC, and the dorsal medial PFC (dmPFC) (Lawrence, Jollant, O'Daly, Zelaya & Phillips, 2008); an area responsible for emotion based moral judgements (Greene, 2001).

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fMRI has also shown activity in the vmPFC is correlated to the value of an object relative to a compared object (Lim, O'Doherty, & Rangel 2011), or with an object's perceived value (Daw et al., 2006, Gottfried et al., 2003, Kable and Glimcher, 2007, Kahnt et al., 2009, Kahnt et al., 2010; Kim et al., 2006; Kahnt, Heinzle, Park & Haynes, 2011; Yacubian et al., 2006). Additionally, there is evidence that clusters of neurons in the vmPFC relate to positive or negative valence (Amarante & Laubach, 2014) and animal studies show different neurons fire for positive and negative values, and these neurons are capable of down regulating one another such that value represented by one cluster will inhibit the activation of clusters relating to the opposite value (Kennerley et al., 2009; Kobayashi et al., 2010; Morrison and Salzman, 2009; Padoa-Schioppa and Assad, 2006; Schoenbaum et al., 2007). That is not to say vmPFC is responsible for all aspects of valuation, animal models suggest that associating values between discrete cues and behavioural responses such as Pavlovian conditioning (Izquierdo, 2004; Gallagher, McMahan, & Schoenbaum, 1999; Ostlund & Balleine, 2007; Gremel & Costa, 2013), recognising changes in value between a cue and an association (Gremel & Costa, 2013), or the selection of previously familiar values (Izquierdo, 2004; Rolls, Hornak, Wade, & McGrath, 1994) are primarily caused by other regions. Moreover behaviour which is indirectly necessary for some instances of valuation like inhibition are well established to be located outside the vmPFC (Aron, Robbins & Poldrack, 2014). It should be noted that regions related to decision making are highly connected with the vmPFC (Roy, Shohamy & Wager, 2012). However the vmPFC is necessary for value discrimination between similar stimuli (McDannald, 2005; McDannald, Lucantonio, Burke, Niv, & Schoenbaum, 2011), for adapting new associations to previously associated value-stimuli relationships (Gottfried, O'Doherty, & Dolan, 2003; O'Doherty et al., 2000), and for associating values and value identity (McDannald, Lucantonio, Burke, Niv, & Schoenbaum, 2011). This suggests that

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although typical emotional functions are not processed in the vmPFC, there is strong evidence that it is involved in conceptual learning aspects of 'higher cognition' by combining historical and immediate values in order to simulate a decisions outcomes (Bechara, 2005).

According to the somatic marker hypothesis somatic feedback is necessary for decision recognition and abstract value retention; this position is largely supported by neurological evidence. Lesion evidence has implicated the vmPFC in directing attention towards features associated with a stimuli of value (Vaidya & Fellows, 2015) and this impairment was not found in other PFC lesion patients. Additionally vmPFC lesioned monkeys appear to have impairments in transitivity (Padoa-Schioppa, 2009), that is to say when several stimuli are evaluated first in order of rank through paired comparison (e.g. A is better than B, B is better than C), and then the stimuli are presented simultaneously in an arbitrary order, vmPFC lesioned monkeys are more inclined to violate previously established orders. This suggests that the vmPFC is responsible for simulating the outcome response to decisions with multiple associations or multiple levels of value. The evidence supports the somatic marker hypothesis by indicating a secondary role of attentional control in selecting conceptually related stimuli, and maintaining abstract relationships between stimuli.

In total this evidence is in line with the somatic marker hypothesis which suggests the occurrence of intra-cerebral connections which simulate a set of responses as part of the "as if body loop" that prompts somatic and motor region activity (Bechara & Damasio, 2005). For example when considering an illegal driving manoeuvre, emotions related to getting caught by the police, such as fear, are contextually associated and therefore are elicited, this influences the decision outcome. The evidence suggests functional specificity of the vmPFC for integrating emotions from various regions of the brain. Therefore the function that is primarily measured by the Iowa gambling task is the capacity

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to simulate and interpret signals which relate to the order of preference between distinct but similar values. This contrasts with the multiple component model and questions whether working memory is essential in integrating information and simulating a decision outcome.

The necessity of emotion to translate observation to behaviour highlights the limited influence of executive function on performance on decision making (Toplak, Sorge, Benoit, West, & Stanovich, 2010). Disassociation between these two factors are seen in addictive behaviours such as smoking wherein emotional impulses influence behaviour over conscious deliberation (Verdejo-García & Bechara, 2009). Similarly this can be seen in Iowa gambling task when specific questions elicit conscious awareness of deck outcomes, but participants continue to choose the disadvantageous decks (Maia & McClelland., 2004). This reflects the finding previously described in vmPFC damaged patients who exhibited greater conscious awareness but still made worse Iowa gambling task decisions (Bechara et al., 1994). Furthermore decision patterns remain similar for an analogue of the Iowa gambling task that presents decision outcomes rapidly (Peatfield, Turnbull, Parkinson, & Intriligator, 2012), suggesting a limited involvement of slow effortful conscious consideration in the actual decision outcome. Turnbull, Berry, and Bowman (2003) removed the experiential reinforcement component by tasking participants to rate hypothetical firefighter actions that were previously rated and ordered in the same reward schedule as the Iowa gambling task. They found participants did not learn in the absence of overt reward or punishment outcomes. This suggests remembering the actions of each firefighter and consciously considering the outcome using working memory was not sufficient to facilitate learning, therefore somatic markers that relate to outcomes are necessary to facilitate complex decision making. However it could be argued that the firefighter's behaviour is too complicated to remember or caused distraction and increased working memory load.

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2. Somatic markers can covertly or subconsciously influence behaviour on complex tasks in the absence of awareness.

This claim is pertinent to the current thesis insofar as it highlights the separation between emotion based processing which is fast and automatic and working memory which is believed to require time and conscious effort (Evans & Stanovich, 2013). This assumption was originally evidenced by simply asking participants why they made a decision in various phases during Iowa gambling task. Bechara et al (1997) found that for healthy controls the Iowa gambling task typically contains four phases of processing, pre-punishment phase; participants have only experienced rewards, 'pre-hunch' phase; participants appear unaware which deck is favourable, the 'hunch' phase; participants report that they 'feel' a deck is 'good' but do not explicitly know why, and 'conscious' or 'conceptual' awareness phase; participants report explicit knowledge of which deck is advantageous. Not all healthy participants achieve this phase when performing the original task that consists of 100 trials, although healthy participants select the good deck slightly more than the bad deck during the pre-hunch phase, and again more frequently during the hunch phase. Patients with damage to the vmPFC or amygdala do not develop hunches and continually choose the bad deck. Bechara et al (1997) argue that preference towards a deck that is advantageous occurs prior to conscious knowledge and is therefore subconscious. By the end of the Iowa gambling task 30% of healthy participants failed to achieve the conscious awareness phase but still acted advantageously, whereas 50% of the vmPFC patients achieved conscious awareness and failed to act advantageously (Bechara et al., 1997).

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This is contested by Maia and McClelland (2004) who found conscious knowledge of Iowa gambling task outcomes when explicitly asking which decks are advantageous, participants listed the number of losses overall, the average losses, and certainty of success. They argue participants calculate the advantageous deck and this consideration shapes the response. However Persaud, McLeod, and Cowey (2007) argue these questions instigated conscious consideration, they used willingness to wager on deck selection as a measure of outcome awareness and found that Maia and McClelland's questions increased willingness. Konstantinidis and Shanks, (2014) replicated Persaud et al's study three times, they reported that questions increase betting in two out of three replications, questions did not increase betting when an Iowa gambling task analogue was used that initially provided punishments to bad deck selection; the initial reward for bad decks is a factor necessary to test complex rather than Pavlovian conditioning (Schoenbaum, Takahashi, Liu & McDannald, 2011; Stalnaker, Cooch & Schoenbaum, 2015). They used measures of confidence and explicit questioning to measure the extent wagering indicates awareness and somewhat counterintuitively suggested that wagering is a poor measure of conscious awareness because it is confounded by loss aversion, a presumably emotional factor. It has been argued that confidence is also an emotion (e.g. Barbalet, 2011), it relates to measures of state anxiety and physiological arousal (Abel & Larkin, 1990), and is colloquially described as such, for example 'I feel confident of success'. Additionally worry is an emotional factor that is associated with greater confidence in decisions (Massoni, 2014) and has been associated to greater Iowa gambling task performance (Mueller, Nguyen, Ray & Borkovec, 2010), although this result has not been replicated (Drost, Spinhoven, Kruijt & Van der Does, 2014). Regardless it is reasonable to suggest the questions could have related to performance by increasing confidence through prompting worry and resolution.

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Summary.

The somatic marker hypothesis (Bechara & Damasio 2005) provides a novel perspective to decision making by describing the factors which dictate the executive functions; the as-if bodily loop. The somatic marker hypothesis primarily uses a multiple choice gambling task the Iowa gambling task to test its three predictions. It describes how physiological signals guide behaviour through the interpretation of markers that relate to previously associated outcomes, which then produces either a decision or further deliberation. Firstly there is neurological evidence that somatic markers guide decision making, although the exact mechanism is still unknown (Phelps, Lempert & Sokol-Hessner, 2014). Secondly somatic markers can make experientially based complex decisions without conscious deliberation. While it is difficult to test the role of conscious cognition with questions without confounding the results by influencing the level of conscious awareness by triggering reflection (Konstantinidis & Shanks, 2014), a task where decisions are made too quickly for conscious deliberation indicates it has a secondary role (Peatfield, Turnbull, Parkinson, & Intriligator, 2012). Thirdly conscious deliberation without somatic markers is not sufficient to motivate a behaviour. Evidence for this claim is supported by lesion evidence, instances of consciously aware participants making disadvantageous decisions, and the failure of participants without definite outcomes to form a preference. Therefore performance on the Iowa gambling task will be considered an indication of the capacity to interpret somatic signals for the purpose of this thesis.

Anxiety and Complex Decision Making

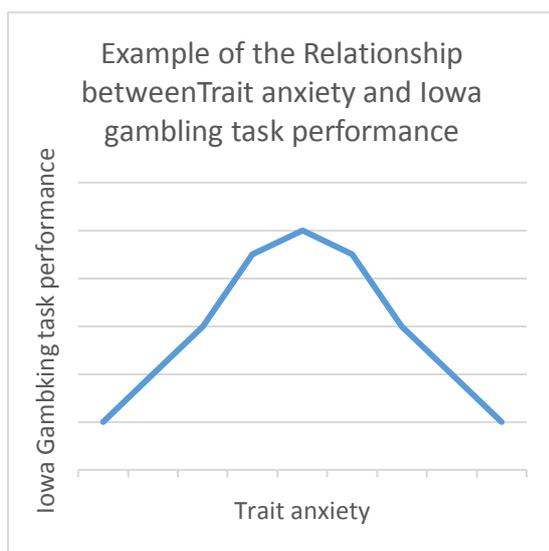
It is well accepted that anxiety is related to impaired executive function as previously discussed (Moran, 2016), and dual process theory argues that working memory is necessary for decision making (Eysenck et al, 2007), this will be discussed in the following section. Additionally the emergence of evidence that suggests emotion is also central to decision making (Bechara & Damasio, 2005) it is logical that anxiety would have an impact on decision making. At the time of writing this thesis eight studies have examined the relationship between anxiety and decision making performance using the Iowa gambling task (e.g. Zhang, Wang, Zhu, Yu, & Chen, 2015). This section highlights differences in study design in order to explain the high level of inconsistency between experiments before considering indirect evidence that anxiety is related to Iowa gambling task performance and complex decision making.

As mentioned previously, anxiety negatively relates to working memory (Moran 2016), and executive function related neural activity (Schienle, Ebner, & Schäfer, 2011), therefore according to the multiple component model and by extension the attentional control theory, trait anxiety would negatively predict performance on decision making tasks which have high attentional control demands.

Superficially, the somatic marker hypothesis appears to make a different prediction as it posits somatic markers indicate value before conscious awareness. Therefore because high trait anxiety is related to greater emotional reactivity, these stronger signals would generate adaptive decisions earlier in the task. This means trait anxiety could positively relate to performance on the Iowa gambling task according to the somatic marker hypothesis. However the somatic marker hypothesis also posits 'background' somatic states influence the strength of signals that relate to primary inducers, and increase the strength of secondary inducers that relate to a congruent somatic state

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(Bechara & Damasio, 2005). In traditional cognitivist terms a negative mood increases the probability of negative cognition and conversely for positive moods. High trait anxiety is related to negative perceptions of arousal (Blair et al., 2008) thus signals that indicate the strength of reward would be discounted while emphasising the significance of losses which could encourage deck switching. Similarly low trait anxiety is related to reduced emotional responsiveness to aversive stimuli (Clark, Mackay, & Holmes, 2014). Therefore the somatic marker hypothesis might argue trait anxiety and lowa gambling task performance should follow an inverted U curve with poorer performance relating to either low emotional responsiveness associated with low trait anxiety, or negative perceptual biases present in high trait anxiety would result in worse performance.



The relationship between lowa gambling task performance and anxiety.

In terms of individual studies the most frequently reported finding is that anxiety relates to more advantageous decisions. However aspects of the experimental designs suggest these results should be interpreted with caution. Trait anxiety was positively correlated with lowa gambling task in a student

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sample (n=64, age: M=23) (Werner, Duschek, & Schandry 2009), in adults (n=30 age: M=48), and children (n=67, age: M=10.43) (Kirsch, & Windmann, 2009). Prisoners who scored highly on a non-clinical measure of anxiety (n=157) (Schmitt, Brinkley, & Newman, 1999), students who were separated into groups by high, medium, and low anxiety (Pajkossy, & Racsmány 2014), and students who meet criteria for general anxiety disorder on a self-report diagnostic measure (n=47, age: M=19) (Mueller, Nguyen, Ray, & Borkovec, 2010), were more adaptive on the Iowa gambling task than less anxious comparisons. Werner, Duschek, and Schandry (2009) reports greater GSR in high trait anxiety, and that in the use of emotional regulation strategies negatively related to performance and GSR changes. They suggest this supports the importance of somatic markers and emotions in making complex decisions, and that regulating emotions during the Iowa gambling task and similar ambiguous situations can result in disadvantageous behaviour. Mueller, Nguyen, Ray, and Borkovec (2010) found the same relationship using an Iowa gambling task analogue with inverted contingencies such that the disadvantageous decks provided frequent but small losses and the advantageous deck incurred large infrequent losses. They posit anxiety is related to greater sensitivity towards unpredictable future losses rather than reward, and cite that general anxiety has been correlated with enhanced formation of negative valence associations (Zinbarg & Mohlman, 1998).

This trend appears to partially support the somatic marker hypothesis but the limitations of these studies should be considered. Unlike studies that report contrary results Werner, Duschek, and Schandry (2009) directly correlated trait anxiety scores with Iowa gambling task performance. This analysis does not consider high anxiety scores that are argued to closely relate to depression and anxiety disorders (Sandi & Richter-Levin, 2009). Nevertheless this indicates greater emotional reactivity may indeed improve performance. Schmitt, Brinkley, and Newman (1999) used a prison

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population which has been found to relate to higher impulsivity, risk taking (Eysenck & McGurk, 1980), reduced set shifting and working memory (Meijers, Harte, Jonker, & Meynen, 2015), it could be that trait anxiety is predictive of low gambling task performance for participants with lower executive function. That is to say participants with greater executive function and low emotional reactivity may adapt their strategy to include more cognitive deliberation.

Additionally the extreme levels of stress experienced by prisoners (Haney 2012) may induce a negative background somatic state causing an imbalanced perception of negative stimuli irrespective of trait anxiety score. Finally it is unclear why an analogue of general anxiety positively related to performance in Mueller, Nguyen, Ray, and Borkovec's (2010) study, although unlike studies that found anxiety has a negative relationship with decision making they did not separate low anxiety from medium anxiety, potentially reducing the performance of the control group. Additionally, the experiment employed a measure of anxiety that most strongly correlates with worry and is less associated with social anxiety than other anxiety measures (Luterek et al., 2002). This is relevant as negative emotional stimuli have been shown to be processed differently in social anxiety (Blair et al., 2008), and worry has been related to greater performance (Mueller, Nguyen, Ray & Borkovec, 2010).

Support for the somatic marker hypothesis has been found by Zhang, Wang, Zhu, Yu, and Chen (2015) who examined high trait anxiety, medium trait anxiety, and low trait anxiety (n=304), and reported a nonlinear relationship between trait anxiety and low gambling task performance when selecting extreme trait anxiety levels from a large sample of students (n=642, age: M=19.17, SD=1.29). Medium trait anxiety predicted the highest performance while low trait anxiety and high trait anxiety displayed similar overall performance. Low trait anxiety related to more frequently choosing the infrequent higher rewards (deck B); which the authors argue indicates a focus on short term rewards and a

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failure to develop a long term strategy. Whereas high trait anxiety related to more frequently choosing smaller frequent rewards and greater losses (deck A); which Damasio (1994) argues indicates a severe impairment in valuation capacity. These results cannot be considered in relation to somatic feedback and it could be that loss size was ignored in high trait anxiety or large punishments were avoided in low trait anxiety, this seems unlikely. Previous research indicates reward magnitude is emphasised and losses are deemphasised in low trait anxiety, while for high trait anxiety reward magnitude is deemphasised and losses are avoided rather than deemphasised, Werner, Duschek, and Schandry (2009) correlated trait anxiety with physiological arousal indicating low trait anxiety relates to reduced somatic feedback during Iowa gambling task deck selection, additionally high trait anxiety relates to greater somatic responses to both rewards and losses (e.g. de Visser et al., 2010) and is related to behavioural avoidance (Eysenck & Van Berkum, 1992). Moreover White, Ratcliff, and Vasey (2015) found evidence that threatening word recognition is impaired in anxiety patients when semantic similarity between distractors is high but not low, which suggests differentiating between negative stimuli can be impaired in anxiety. Finally behavioural activation, sensation seeking, and impulsivity are related to low trait anxiety and deck B preference (Buelow & Suhr, 2013). This supports the somatic marker hypothesis which suggests somatic awareness in the absence of avoidance behaviour predicts Iowa gambling task performance.

On the other hand Pajkossy, Dezső and Zoltay Paprika (2009), Miu, Heilman, and Houser (2008), and de Visser et al. (2010) report a negative relationship between Iowa gambling task and trait anxiety. Pajkossy, Dezső and Zoltay Paprika (2009) found that high state anxiety improved performance ($n=50$ age: $M=23.82$, $SD=3.31$). Interestingly unlike trait anxiety state anxiety is not related to working memory (Lewis, Nikolova, Chang, & Weekes, 2008) and suggests trait differences rather than state

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anxiety could be a factor that determines complex decision making performance, potentially through reduced working memory. Miu, Heilman, and Houser (2008) found high trait anxiety correlated with greater heart rate deceleration and higher GSR variability but worse performance, although the study did not examine medium levels of anxiety but compared extreme high and low trait anxiety scores. This indicates high levels of anxiety can impair performance to a greater extent than in low trait anxiety but does not reflect the effect of moderate differences. These studies suggest extreme levels of trait anxiety predispose negative somatic responses, and mediates the beneficial role of somatic reactivity in predicting differences in Iowa gambling task performance.

The nonlinear relationship between anxiety and Iowa gambling task could also explain results reporting no relationship. Rocha, Alvarenga, Malloy-Diniz, and Corrêa, (2011) examined Iowa gambling task performance and trait anxiety in obsessive compulsive disorder (OCD) patients, and controls that were matched for intelligence and demographics. OCD is related to working memory and executive function impairments (Snyder, Kaiser, Warren & Heller, 2015) therefore the lack of relationship compared to Werner, Duschek, and Schandry (2009) could indicate anxiety improves decision making only at higher levels of executive function. It is in accordance with the both dual process theories and somatic marker hypothesis that lower executive function relates to impaired emotional regulation (Bechara & Damasio, 2005; Evans & Stanovich, 2013). Moreover both disadvantageous decision making at high trait anxiety and low trait anxiety found by Schmitt, Brinkley, and Newman (1999) could confound the relationship when directly correlating the measures.

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The role of emotional processing in the relationship between anxiety and Iowa gambling task performance.

There is also evidence to suggest persistent anxiety is related to the emotional aspects of decision making rather than as a facet of coinciding executive dysfunction. As described in previously anxiety perhaps counterintuitively correlates with impulsive behaviour, which can incur detrimental long term consequences and mirrors behaviour reported of vmPFC patients in some cases. Greater responsiveness (LaFreniere 2016) and physiological reactivity towards action contingent reward related stimuli (Paulus & Yu, 2012), and poorer aversive stimuli discrimination (Lissek, 2012) have also been reported in anxiety. According to the somatic marker hypothesis differences in reactive emotional responses could translate into differences in synthesising value representations when generating intuitive responses. Therefore somatic markers could be the cause in Iowa gambling task performance differences between medium and higher levels of trait anxiety, rather than differences in components of executive function. In support of this Zhang, Wang, Zhu, Yu, and Chen (2015) found risky decision making, which is related to executive control (Krain, Wilson, Arbuckle, Castellanos & Milham, 2006), did not related to trait anxiety, whereas complex decision making did. This suggests evidence of decision making deficits in trait anxiety could be explained by deficits in working memory, and that the emotional component of decision making is not impaired when making ambiguous decisions.

Considerable neurological support that trait anxiety relates to impaired emotional aspects of decision making has also been found; EEG has shown that event activity related to errors in response accuracy tasks that are time limited, is consistently greater for trait anxiety, and reflecting trait anxiety these differences are consistent over time (Hajcak, 2012). fMRI imaging suggests anxiety relates to

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differences in affective regions employed during the Iowa gambling task (Telzer et al., 2008); such as the amygdala, insula cortex (Stein, 2007), vmPFC, posterior ACC (Xu et al., 2013) and the dmPFC whose activity positively correlates with task performance (Lawrence, Jollant, O'Daly, Zelaya & Phillips, 2008), although differences in dlPFC during task engagement were also been reported. Rodent analogues of Iowa gambling task have shown that anxiety impairs performance in rats (Bos, Koot & Visser, 2014). Infusing vmPFC with affect regulating neuropeptide corticotrophin releasing factor (CRF) (Heinrichs & Koob, 2004) causes context related stress avoidance behaviour (Schreiber, Lu, Baynes, Richardson & Gilpin, 2017), and CRF is dysregulated in anxiety and other affect related disorders (George & Koob, 2010) suggesting anxiety could relate to good performance through stress avoidance at a complex decision making level. Together this provides strong evidence that anxiety is related to aspects of decision making through regions which interpret emotions or somatic markers.

Summary

This section has described how anxiety has been inconsistently related to decision making as measured by the Iowa gambling task, the evidence suggests there is a non-linear relationship and high and low levels of trait anxiety relate to worse performance (e.g. Zhang, Wang, Zhu, Yu, & Chen, 2015). This is consistent with self-report measures of poor decision making in real life (e.g. Jacka, Mykletun, Berk, Bjelland & Tell, 2011; Leventhal & Zvolensky, 2015). According to the somatic marker hypothesis this might be due to differences in somatic marker responsiveness and differences in regions responsible for synthesising emotion or value (Bechara & Damasio, 2005), which contrasts with

traditional dual process perspectives of decision making that focus on executive function (Evans & Stanovich, 2013).

Working memory and Complex Decision Making

The somatic marker hypothesis describes the Iowa gambling task as a task that primarily involves integrating reward and loss experiences into value representations generated from somatic feedback, these representations must be maintained throughout the task using working memory (Bechara & Damasio, 2005). According to this view intact working memory is necessary for Iowa gambling task performance, however working memory does not linearly positively relate to performance (Bechara & Damasio, 2005; Bechara, Damasio & Damasio, 2000). The somatic marker hypothesis describes working memory as strengthening representations. Behaviourally this is identical to storing the value of each deck in working memory, however deck values are updated without working memory involvement. Therefore the somatic marker hypothesis predicts somatic markers would primarily determine Iowa gambling task performance while working memory is necessary insofar as it facilitates valuation.

This is in contrast to traditional dual process models of decision making that consider working memory as a central component (Bagneux, Thomassin, Gonthier & Roulin, 2013). It has been suggested that “decision strategies in the Iowa gambling task rely almost exclusively on acquired conscious knowledge about the properties of the decks” (Konstantinidis & Shanks, 2014, p. 51) suggesting mental manipulation and maintenance of outcome values is necessary. Thus working memory would directly relate to performance. Accordingly emotional factors such as trait anxiety or outcome related arousal would have an effect insofar as they impede working memory processing.

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Working memory and Iowa gambling task.

Research which has aimed to examine the working memory and Iowa gambling task relationship the effect of concurrent high or low working memory loads on Iowa gambling task performance have been compared. The results from this paradigm are inconsistent; some studies reported no impact of working memory load (Turnbull, Evans, Bunce, Carzolio, & O'Connor, 2005; Gozzi, Cherubini, Papagno, & Bricolo, 2010) while others using greater load found reduced performance (Dretsch & Tipples, 2008; Hinson, Jameson, & Whitney, 2002; Jameson, Hinson, & Whitney, 2004). Dretsch and Tipples (2008) found working memory load induced a pattern of impulsive choices; they suggest impulsive decision making results from an inability to consciously assess the values in working memory. On the other hand high working memory load impairs Iowa gambling task performance but does not reduce participant's explicit knowledge of deck outcomes (Dretsch & Tipples 2008). This is similar to performance by vmPFC patients who were unable to choose advantageous decks but were still capable of describing which decks are advantageous (Bechara et al., 1997). Therefore high working memory load appears to impair value integration rather than conscious calculation of deck values using working memory. From the perspective of the somatic marker hypothesis it could be argued that the addition of high concurrent working memory demands reduces working memory below the minimum threshold for four somatic value representations to be sufficiently strengthened. Therefore although this adds support that working memory is involved in the Iowa gambling task, this paradigm does not elucidate the relationship contingencies between valuation and working memory, because it could impair the retention of deck values rather than, or in addition to the conscious deliberation of these values. Similarly, experiments using Iowa gambling task analogues designed to apply greater load on working memory also have uncertain implications. Pecchinenda, Dretsch, and Chapman

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(2006) varied deck locations to incur additional spatial processing. They found this resulted in worse performance, which they argue supports the role of working memory in valuation. However removing location as a contextual cue from an outcome could prevent the vmPFC from updating the values associated with the stimuli (Gottfried, O'Doherty, & Dolan, 2003; McDannald, Lucantonio, Burke, Niv, & Schoenbaum, 2011) rather than or in addition to loading working memory. These experiments potentially support the somatic marker hypothesis position that working memory is necessary for value maintenance but not outcome contingency learning through value integration. That is to say altering the Iowa gambling task to incur additional working memory demands may also interfere with non-working memory processes that rely to some extent on attention and therefore does not describe the qualitative relationship of valuation with complex decision making.

Correlation between working memory and Iowa gambling task.

In order to examine the relationship between working memory and complex decision making without compromising the what the Iowa gambling task measures it could be useful to examine correlations between working memory and Iowa gambling task performance. Several studies have examined the influence of working memory on Iowa gambling task performance. Most studies primarily examined the relationship between a mental illness or a neurodegenerative disorder on Iowa gambling task performance (Toplak, Sorge, Benoit, West, & Stanovich, 2010). In these studies working memory performance scores were correlated with Iowa gambling task performance within or across groups, a 2010 review examined 25 experiments from 15 articles and found only 4 instances where working memory correlated with Iowa gambling task performance (Toplak, Sorge, Benoit, West, & Stanovich, 2010). Since then other studies have reported a significant positive relationship between working

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memory and Iowa gambling task performance in schizophrenic patients and controls (Brown et al., 2015), in multiple sclerosis patients (Farez, Crivelli, Leiguarda, & Correale, 2014), and in children between 6-11 (Audusseau & Juhel, 2015), although a different study using longitudinal data found this relationship does not follow a developmental trajectory (Smith, Xiao, & Bechara, 2012), which suggests working memory contributes to performance to a greater degree than the development of other psychological processes. Non-significant relationships have also been reported, in borderline personality disorder and controls (LeGris, Toplak, & Links, 2014).

Moreover, using multiple complex span tasks Bagneux, Thomassin, Gonthier and Roulin (2013) found Iowa gambling task scores differed between high working memory and low working memory groups, they found low working memory resulted in worse performance. Specifically low working memory participants performed worse from the hunch period (block 3), according to the somatic marker hypothesis this could suggest working memory capacity relates to the ability to create hunches through maintaining separate deck representations. Moreover a necessary working memory threshold would produce a nonlinear trend and could explain instances where direct correlations failed to find a relationship. Interestingly high working memory participants do not perform better during the final block, which suggests another factor may affect performance, such as low engagement; this too could explain the failure to detect a relationship in studies which directly correlate Iowa gambling task scores with working memory.

The individual differences method potentially has significant advantages over loading working memory as it does not directly interfere with the valuation process. Individual differences in other executive functions have been compared to Iowa gambling task performance. Set shifting (Dong, Du, & Qi, 2016; Rutz, Hamdan, & Lamar, 2013), monitoring and inhibition (Del Missier, Mäntylä, & Bruin,

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2011), and IQ (Toplak, Sorge, Benoit, West, & Stanovich, 2010) have also been weakly and inconsistently correlated to Iowa gambling task scores, which suggests a coinciding factor might exist between Iowa gambling task performance and executive function.

Neurological evidence of the role of working memory in Iowa gambling task performance

Another method of examining the influence of working memory on decision making is by considering the involvement of the neural regions responsible for working memory in Iowa gambling task.

Bechara, Damasio, Tranel, and Anderson (1998) reported a striking finding that lesions to the region responsible for working memory (dlPFC) improved Iowa gambling task performance, however this finding was not replicated (Manes et al., 2002; Fellows, 2004). This has three implications; firstly it highlights the role of working memory in valuation, secondly it indicates that both working memory and somatic value feedback is necessary to successfully perform the Iowa gambling task, thirdly the working memory system is involved during the 'hunch' period when participants perform advantageously but cannot report conscious awareness. Further support for the involvement of aspects of working memory in the Iowa gambling task comes from increased dlPFC activation during the task (Li, Lu, D'Armentano, Ng, & Bechara, 2009). Unlike other regions, greater dlPFC activation is not related to task processing (Lawrence, Jollant, O'Daly, Zelaya & Phillips, 2008), potentially supporting the role of working memory as a necessary aspect of valuation insofar as it is required to retain deck values, but does not directly relate to the valuation aspects of task performance.

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Alternative theories that explain the relationship between complex decision making and working memory.

Researchers have attempted to reconcile the limited involvement of working memory in decision making by offering different mechanisms that determine the influence of working memory on the Iowa gambling task. The tripartite theory by Stanovich (2009) argues that conscious processing is responsible for valuation in line with standard dual process models, but that other capacities are required to initiate this process. It posits differences in the susceptibility to heuristics and biases are responsible for differences in performance, which they refer to as rationality or cognitive reflection. This perspective has successfully measured a large amount of Iowa gambling task performance (Simonovic, Stuppel, Gale, & Sheffield, 2017), although this measure also relates to working memory (Morsanyi, Busdraghi & Primi 2014). Therefore differences in rationality could determine whether working memory is applied to the task, meaning it could mediate the relationship with Iowa gambling task performance. The fuzzy trace theory of decision making by Reyna and Brainerd (2011) similarly posits moderating factors for the role of working memory in decision making. They argue that decision making differs between individuals based on the propensity to use thinking styles that rely on intuition or detailed analysis. Gist or intuition based thinking is contrasted with so called verbatim thinking. It is argued that verbatim thinking is devoid of value and is more susceptible to failures of inhibition compared to gist based thinking, while gist based thinking is more general, can relate to emotion and is more likely to motivate behaviour. Gist based thinking differs from predictions made by the somatic marker hypothesis as the theory argues the use of gist or intuition based thinking would reduce performance in the Iowa gambling task, while verbatim based thinking would relate to greater performance (Hawthorne & Pierce, 2015). This relationship has been supported by

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developmental trends that find greater performance is found throughout adolescence, a period related to gist based thinking, and increasing working memory capacity increases throughout that period (Huizinga, Dolan & van der Molen, 2006). In contrast older adults tend to employ gist based thinking, and perform worse than younger adults (Fein, McGillivray & Finn, 2007). This suggests differences in thinking styles could moderate the relationship between working memory and Iowa gambling task performance.

Summary.

The relationship between executive function and Iowa gambling task performance is strikingly inconsistent, which suggests the existence of an additional factor. Poor performance under high load (Dretsch & Tipples, 2008) indicates working memory is necessary to facilitate performance, however the additional task might interfere with non-working memory processes. The extremely small and infrequent direct correlation between working memory and Iowa gambling task, and the report that low working memory capacity relates to worse Iowa gambling task performance compared to high working memory, suggests the existence of a non-linear relationship. The somatic marker hypothesis suggests working memory is necessary only insofar as it strengthens deck representations. The failure to correlate dlPFC activity with performance (Lawrence, Jollant, O'Daly, Zelaya & Phillips, 2008), support the existence of a working memory threshold that facilitates but does not determine performance.

Current Aims

This thesis aims to measure the relationships between complex decision making measured using the Iowa gambling task, working memory, and trait anxiety because previous research has reported empirically inconsistent relationships (Bagneux, Thomassin, Gonthier & Roulin, 2013; LeGris, Toplak, & Links, 2014; Toplak, Sorge, Benoit, West, & Stanovich, 2010; Werner, Duschek, & Schandry 2009; Zhang, Wang, Zhu, Yu, & Chen 2015). Trait anxiety consistently relates to working memory (Moran, 2016) and trait anxiety appears to have a non-linear relationship with Iowa gambling task. This is in contrast to predictions made by both the somatic marker hypothesis and the attentional control theory that suggest working memory, trait anxiety, and Iowa gambling task performance are interconnected, although in qualitatively different ways (Bechara & Damasio, 2005; Evans & Stanovich, 2013).

Hypothesis one: Working memory will positively correlate with Iowa gambling task performance.

The evidence suggests there is a relationship between individual differences in working memory and Iowa gambling task performance is inconsistent (e.g. Farez, Crivelli, Leiguarda, & Correale, 2014; Toplak, Sorge, Benoit, West, & Stanovich, 2010), however there is experimental evidence that manipulates working memory requirements and neurological evidence (Dretsch & Tipples, 2008; Hinson, Jameson, & Whitney, 2002; Jameson, Hinson, & Whitney, 2004) that supports this relationship. Additionally this relationship is posited by dual process theories (Evans & Stanovich, 2013).

Hypothesis two: Trait anxiety will negatively correlate with working memory

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The study aims to replicate the well-established finding that trait anxiety is correlated with working memory (Moran 2016). This relationship is central to dual process theories of anxiety such as the attentional control model (Eysenck et al, 2007), and has support from neurological (Hoshino 2015), experimental (Moran 2016; Sears 2014) and clinical evidence (Hadwin and Richards, 2016).

Hypothesis three: Trait anxiety will negatively correlate with Iowa gambling task performance.

Although a study found high trait anxiety relates to worse performance, the study compared low, and high trait anxiety (Miu, Heilman, & Houser 2008), whereas the majority of studies found trait anxiety related to greater performance, and this was also related to differences in physiological arousal (e.g. Werner, Duschek, & Schandry 2009), or found that low and high trait anxiety is related to worse Iowa gambling task performance than medium trait anxiety (Zhang, Wang, Zhu, Yu, & Chen 2015). On the other hand trait anxiety has been related to poor real life decision making e.g. DiMatteo, Lepper, & Croghan, 2000). It could be argued some degree of trait anxiety is necessary to facilitate adequate somatic signals. From this perspective trait anxiety should relate to Iowa gambling task performance in a non-clinical sample. In contrast to predictions made that the Iowa gambling task would be highly dependent on working memory, which according to the attentional control theory suggests trait anxiety should negatively correlate with performance due to lower demands on working memory.

Hypothesis four: When analysed together, differences in trait anxiety and working memory will predict Iowa gambling task performance

To date no research has concurrently analysed trait anxiety, working memory, and Iowa gambling task performance in young adults. Kirsch and Windmann (2009) examined this relationship in children and

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found trait anxiety, but not working memory related to Iowa gambling task performance. However recent theory suggests that differences in reasoning styles between adults and children could relate to the utilisation of working memory in decision making due to differences in adapting behaviour using analytical thinking, or the use of rule abstraction (Reyna & Brainerd 2011; Toplak, West & Stanovich, 2014). This means that difference in working memory in children may be unrelated to performance because they did not employ conscious deliberation of deck outcomes. Instead children are argued to rely upon intuitive thinking, which has also been found to differ as a result of development (Icenogle et al., 2016). The reliance on intuitive decision making strategies could mean trait anxiety related to task performance in that sample because of higher somatic responsiveness, and that this relationship is not present in adults who employ analytical decision making strategies. Additionally the instruments the study used to measure working memory (n-back) is at least in part determined by familiarity based responding, and has been related to separate general fluid intelligence variance (Kane, Conway, Miura & Colflesh, 2007). Moreover the measure is only modestly related to valid measures of working memory ($R = .2$) (Redick & Lindsey, 2013), suggesting it tests a different but related concept, possibly due to a reliance on short term memory (Moran 2016).

The relationship between trait anxiety and Iowa gambling task performance is inconsistent but the majority of evidence finds that it positively relates to greater performance (e.g. Werner, Duschek, and Schandry, 2009), similarly a positive relationship has been found between working memory and Iowa gambling task performance (e.g. Farez, Crivelli, Leiguarda, & Correale, 2014; Toplak, Sorge, Benoit, West, & Stanovich, 2010), yet trait anxiety has been related to poorer working memory (Moran, 2016). Therefore it could be that some aspects of trait anxiety relate to advantageous behaviours in the Iowa gambling task, such as an aversion to unpredictable loss (Zinbarg & Mohlman, 1998), but

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that working memory is necessary to protect against aspects of trait anxiety that are maladaptive, such as impulsivity (Xia et al., 2017). This suggests that participants who score highly on measures of trait anxiety who also have high working memory will have greater performance on the Iowa gambling task. Alternatively it could be that working memory and trait anxiety separately predict Iowa gambling task performance, nevertheless there is evidence to suggest the combination of these variables will increase the amount of variance explained.

Hypothesis five: Performance on operation span, symmetry span, and reading span measures of working memory will each relate to trait anxiety

A combination of span tasks were chosen for the primary analysis in order to measure the executive component of working memory rather than a specific domain, it is argued this aspect is connected to complex real life decision making impairments, such as temporal discounting, impulsivity, and goal directed behaviour (Evans & Stanovich, 2013). The position that working memory is limited by separate short term storage capacities has been well established (Baddeley, 2012). Research has found conflicting evidence that particular working memory domains relate to anxiety to a greater extent than other domains. There is evidence that this difference is cultural, samples from East Asia relate anxiety to greater differences in spatial working memory than other populations (Moran, 2016). If trait anxiety only relates to particular aspects of working memory, this could suggest the corresponding task domain is responsible for the relationship between working memory and trait anxiety to some extent. For example the attentional control theory argues task irrelevant thinking is responsible for working memory differences, and this would primarily impact phonological working memory (Eysenck et al., 2007), whereas Robinson, Vytal, Cornwell and Grillon (2013) suggests physiological arousal increases sensory input and loads spatial working memory. Another

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consideration is that context related anxiety such as maths anxiety (Betz, 1978), could confound the results. Therefore the current experiment will examine the relationship between trait anxiety and the separate domains of working memory.

Hypothesis six: Trait anxiety will interact with operation span performance to predict Iowa gambling task performance.

Operation span is a working memory task that requires memorising a series of letters, while performing simple maths equations. The domain used for this task is similar to that which is required of the Iowa gambling task according to tradition dual process theories. Specifically calculating deck outcome would require maintaining deck related information during distraction, and modifying it using simple maths in order to update deck expectancies. Trait anxiety has been similarly related to operation span measures, yet trait anxiety is also related to Iowa gambling task performance. By concurrently examining how these variable relate to Iowa gambling task performance this study aims to elucidate this seemingly contradictory phenomena.

Method

Participants

When the relationship has been found previous research has shown working memory (e.g. Brown et al., 2015; Toplak, Sorge, Benoit, West, & Stanovich, 2010) and trait anxiety (e.g. Werner, Duschek, & Schandry, 2009) explain a small amount of Iowa gambling task performance variance, it was predicted that each variable would explain a unique contribution as they are negatively correlated with one another (Moran 2016). Therefore it is predicted that together working memory and trait anxiety would explain a medium Iowa gambling task performance variance. Using a power calculation programme (Faul et al., 2007) a compromise linear regression power analysis was conducted to determine the implied power of a linear regression analysis with a sample size of 65 in order to discover a medium effect size $F^2 = 0.15$ with two predictors (working memory, Iowa gambling task performance), with a α/β ratio = 4 in order an alpha value close to convention the test would have an implied power of 0.79, $\alpha = 0.052$ and a critical $F(3,62) = 3.093$. From a sample of 65 participants 59 were students at the University of Huddersfield who participated as part of a course requirement, 6 responded to flyers that were distributed within the university. The sample consisted of 24 males and 41 females, age $M=20.69$, $SD=2.57$. A student sample was used for convenience, and because the sample was older than early developmental stages that have been examined in previous research (Audusseau & Juhel, 2015).

Measures

Participants completed the trait section of the State-Trait Anxiety Inventory (STAI-T) (Spielberger, Gorsuch, & Lushene, 1970), a questionnaire with 20 items designed to measure a persistent tendency

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towards anxiety. Participants respond to a Likert scale with four degrees of agreement, from 'almost never' (scores 1) to 'almost always' (scores 4). 10 of the questions are reverse scored. For example, 'I feel nervous and restless', and 'I am cool, calm, and collected'. Low scores indicate low anxiety while high scores indicate high anxiety. To measure working memory participants completed three automated, shortened variants of the complex span tasks; symmetry, operation, and reading span. These tasks involve remembering a series of briefly presented target stimuli; either a letter (reading span), a number (operation span), or the location of a highlighted square on a 9x9 grid (symmetry span), while intermittently responding to distractors; a maths problem (operation span), deciding whether a target sentence made sense (reading span), and deciding whether a grid with shaded squares was symmetrical (symmetry span), see figures 1-6. Practice trials were initially completed, these consisted of separately remembering target items and completing distractor tasks, before a combination of both tasks. In accordance with guidance by Conway et al (2005) participants who failed to achieve an accuracy of 85% on the distracter trials during the practice conditions were excluded from the experiment. In the main experiments the symmetry span consisted of a total of 6 trials with 2 trials of 3, 4, and 5 items to be remembered, whereas reading span and operation span consisted of 6 trials with 2 trials of 4, 5, and 6 items to be remembered. Complex span tasks are widely used as measures of working memory, the shortened variants have been shown to have similar advantages as the original measures; such as high test-retest reliability, high internal consistency, and convergent and discriminant construct validity (Oswald, McAbee, Redick, & Hambrick, 2014). An additional benefit to using the shortened variants is that measuring multiple domains of working memory becomes less demanding, therefore additional tests can be implemented without infringing

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upon the participant's patience. This potentially makes the shortened variant more suitable for individual differences studies.

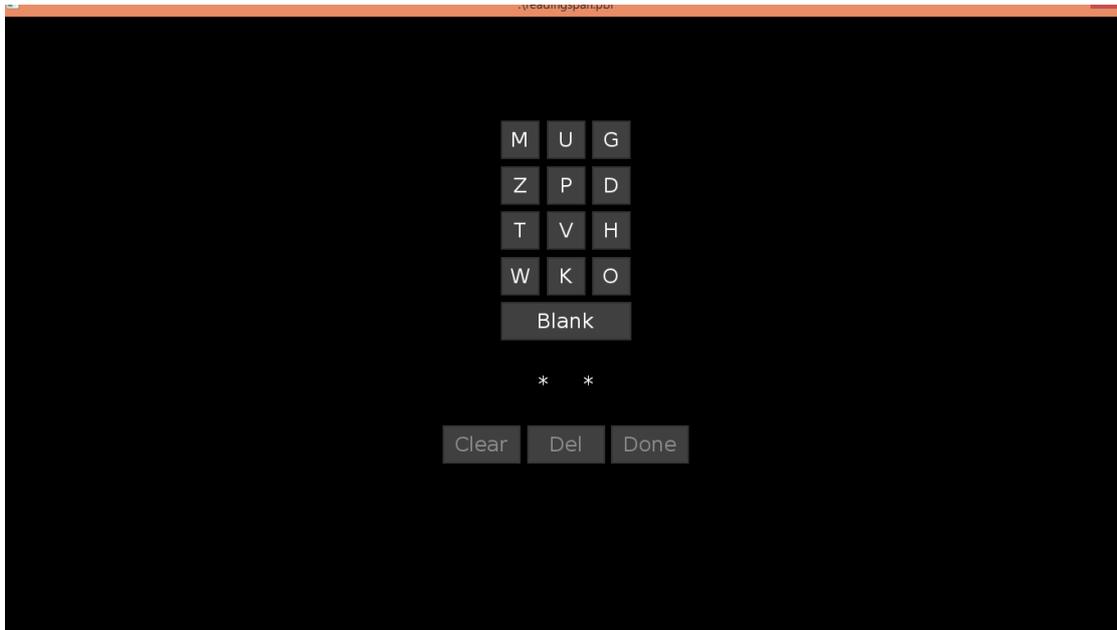


Figure 1 Reading and operation spans response

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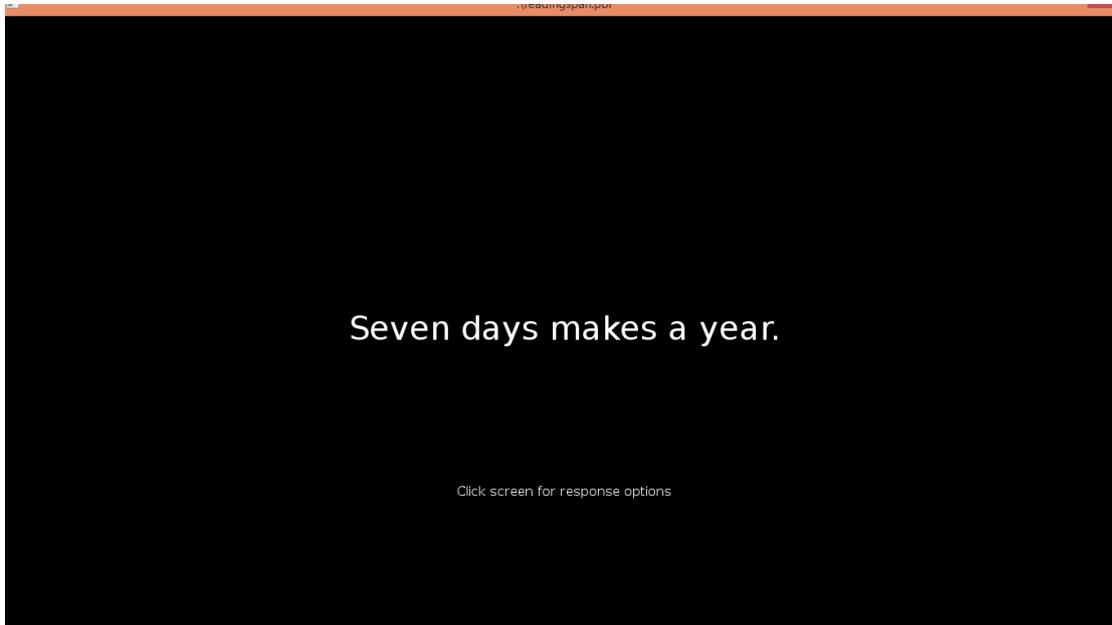


Figure 2 Reading span distractor

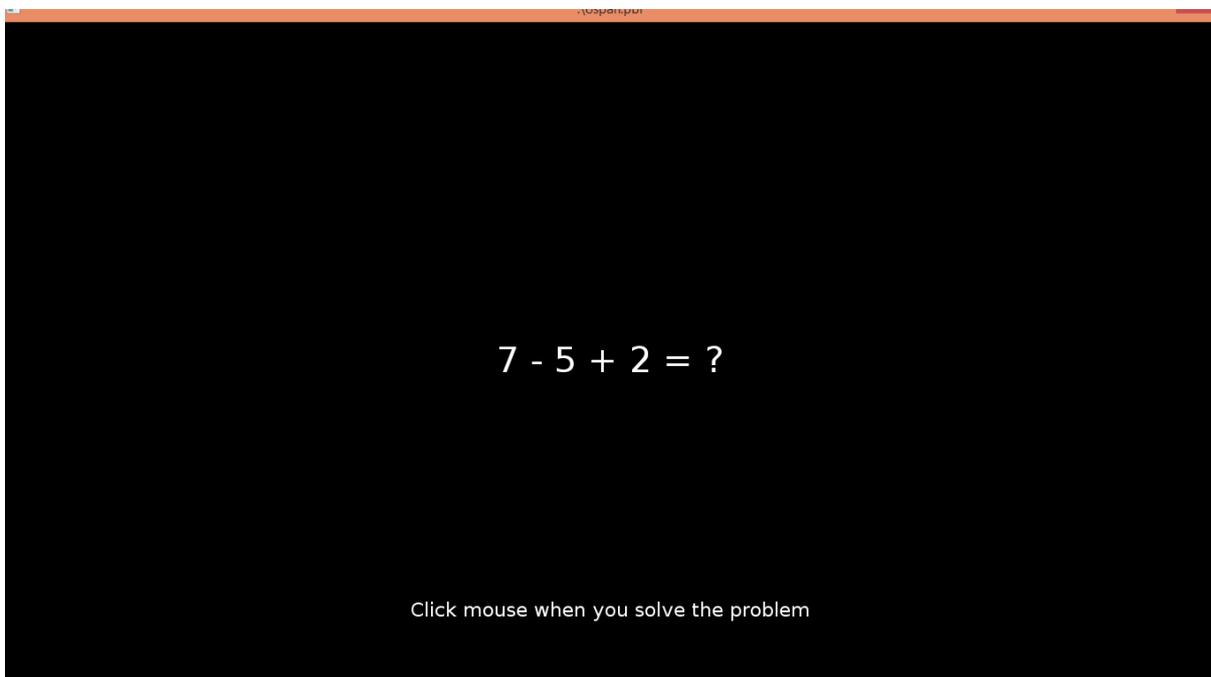


Figure 3 Operation span distractor

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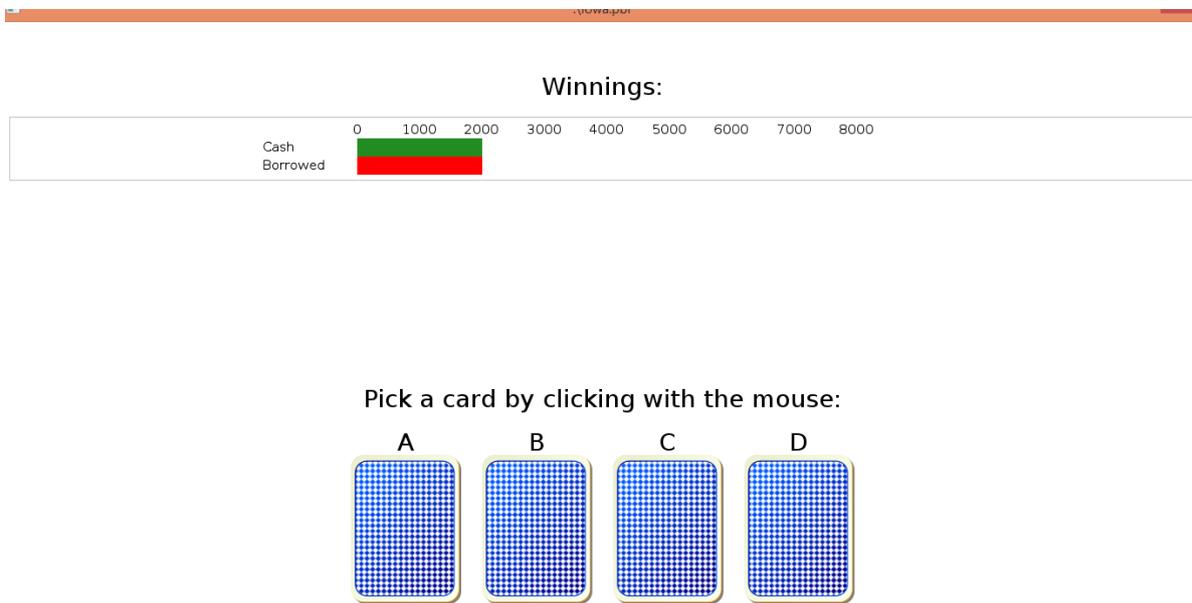


Figure 4 Iowa gambling task

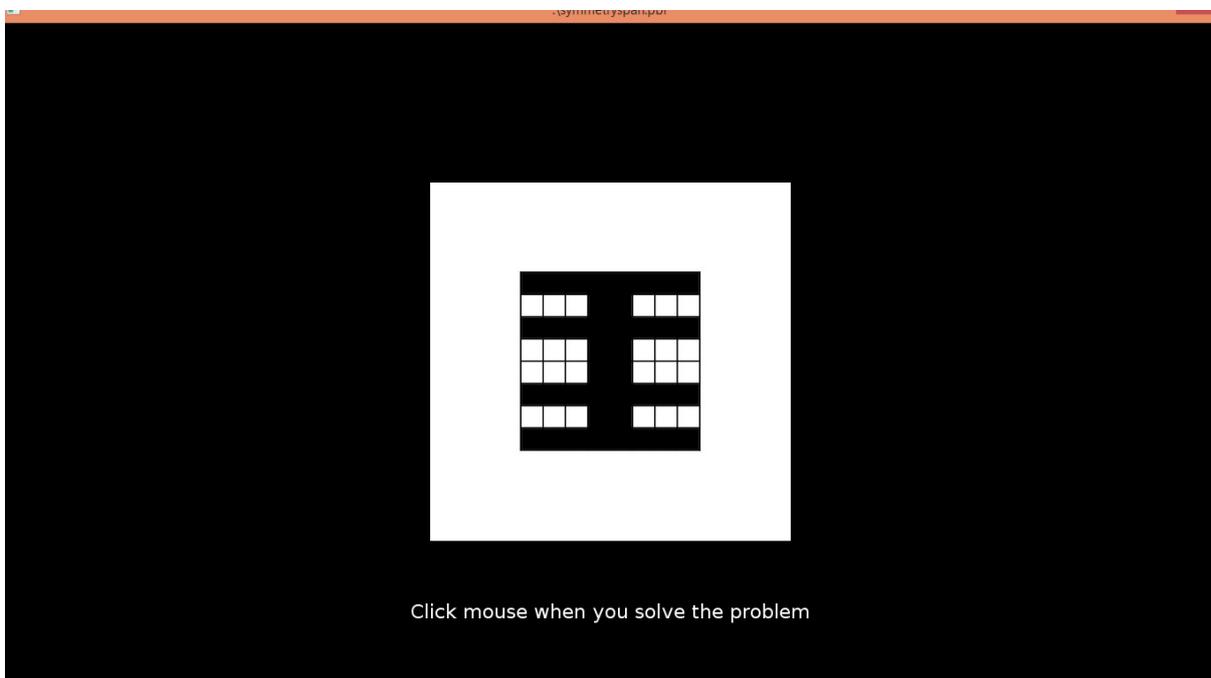


Figure 5 Symmetry span distractor

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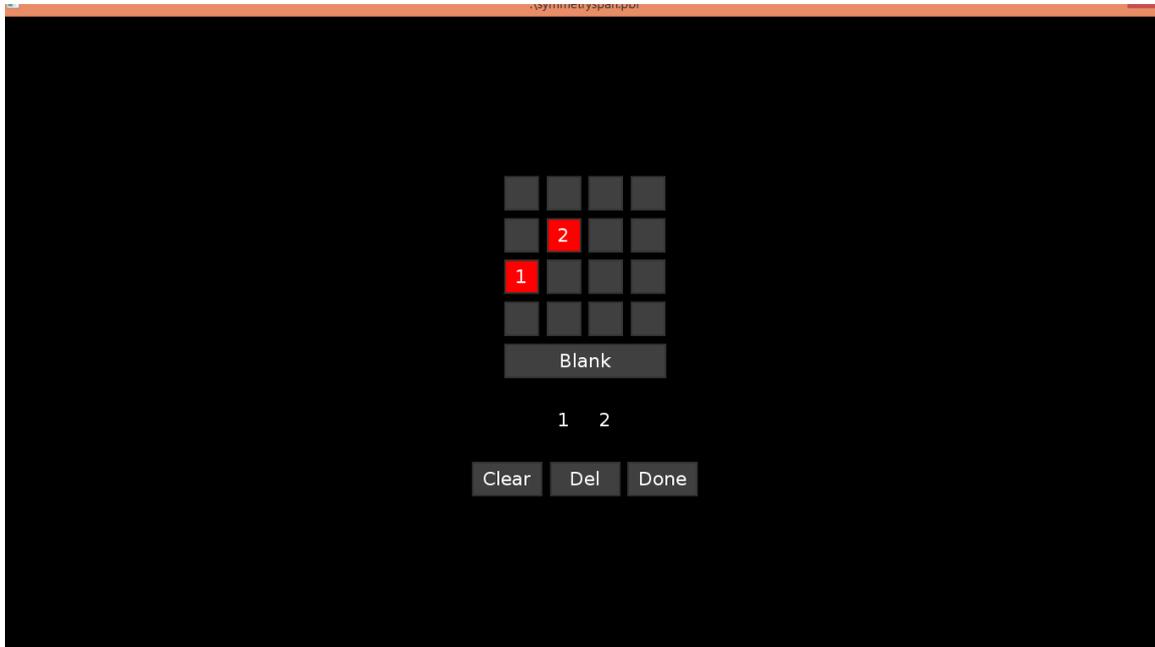


Figure 6 Symmetry span response

Apparatus

The complex span tasks and the Iowa gambling task were run using PEBL v2.0 psychology experiment building software (Mueller & Piper, 2014). Tasks were completed using a mouse on a Fujitsu Lifebook A series laptop, responses were recorded using the PEBL v2.0 software. The laptop was placed on a height adjustable stand.

Design and Procedure

The current study uses a cross-sectional correlational design to examine the correlation between working memory, trait anxiety, and Iowa gambling task performance.

When participants arrived they were asked to read the information sheet and if they had any questions before completing the consent form. Firstly participants responded to the STAI-T, then completed the tasks in the following order; Iowa gambling task, symmetry span, reading span, and

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operation span. A 30 second break was included at the end of each task. All instructions were presented on the computer monitor with the instruction to ask the experimenter questions. The experiment used a computerised variant of the classic Iowa gambling task (Bechara & Damasio, 2005); the participants is asked to repeatedly choose a card from one of four identical decks, immediately after choosing a deck the participant receives either a reward or punishment. Rewards and punishments are accompanied by a happy or sad face respectively, and with an associated sound. Information on overall reward and punishment is provided by two bars indicating gains and debt. Each deck provides a separate quantity and frequency of rewards and punishment. The participant is informed that there are both good and bad decks, and are asked to try to maximise their rewards. The task consists of 100 trials overall although the participant is not informed of the length of the experiment. For a discussion of the construct reliability of the Iowa gambling task.

When participants arrived they were asked to read the information sheet and were if they had any questions before completing the consent form. Firstly participants responded to the STAI-T, then completed the tasks in the following order; Iowa gambling task, symmetry span, reading span, and operation span. A 30 second break was included at the end of each task. All instructions were presented on the computer monitor with the instruction to ask the experimenter questions. An opportunity for questions was provided before the experiment and at the end of each practice phase. Upon secession participants were given a debrief sheet and were asked if they had any further questions. The experimenter was sat behind the participant throughout the experiment. The experiment lasted between 35-45 minutes and only one participant was tested at a time.

Results

The Iowa gambling task scores were analysed by separating each set of 20 trials into blocks, the variable for each block of the Iowa gambling task was constructed from the number of advantageous deck choices minus the disadvantageous choices. In accordance with Bechara et al (1998) the first two blocks are discarded as they reflect the exploratory period before the participant has learned the deck outcomes so the primary analysis uses the sum of the final three blocks.

The complex span tasks scores were measured using partial scoring (Redick et al., 2012) meaning responses that include some errors are scored as a fraction of correct answers, for example correctly responding with three out of five letters is scored as three fifths. A working memory score was derived by standardising the complex span task scores to into a z-score ($x - M / SD$). A combined measure of working memory was used so that the scores were minimally impacted by differences in memory system domains and reflected the executive component of working memory (Duff, 2000). A relatively large number of participants failed to achieve 85% accuracy on the symmetry span distractor task ($n=16$), therefore the task was not included in the composite working memory score for the main analysis. Rather than discarding the entire data set of the participants who failed, the task was removed to increase the power of the main analysis.

The descriptive statistics for the primary analysis were as follows; trait anxiety $M=46.09$, $SD=9.87$, working memory $SD=1.57$, and average final three Iowa gambling task blocks $M=0.43$, $SD=7.97$, and for the separate complex span tasks; $ospan M=4.14$, $SD=1.26$, $rspan M=4.91$, $SD=0.96$, and $sspan M=3.69$, $SD=1.2$. Correlating the separate complex span scores revealed that each measure of working memory significantly correlated with one another, see table 2.

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Table 1

Descriptive Statistics for Iowa Gambling Task Performance by Block

Block	Mean	Standard deviation
1	-3.63	5.07
2	-1.11	6.58
3	1.02	7.07
4	.09	9.13
5	.19	10.26

Table 2

Correlations Between Complex Span Tasks

	Sspan n=49	Ospan n=65	Rspan n=65
Sspan	-	.24*	.51**
Ospan	.24*	-	.23*
Rspan	.51**	.23*	-

* = $p < .05$ ** = $p < .01$

From block 3 participants selected more advantageous choices than disadvantageous choices on average (see table 1). To test whether learning occurred in the Iowa gambling task, a repeated measures ANOVA was conducted to examine performance differences over the course of the task.

The dependent variable was the number of advantageous choices minus the number of disadvantageous choices, and the independent variable was block. Mauchly's test found the

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assumption of sphericity was violated ($\chi^2 = (9) 51.331, p < .001$) therefore degrees of freedom were corrected using Greenhouse Geisser estimates of sphericity ($\epsilon = .699$). The test found significantly more advantageous choices were chosen across the course of the task. ($F(4, 179.01) = 5.723, p = .001$).

Correlations between working memory, trait anxiety, and Iowa gambling task performance

In order to test hypothesis one, two, and three a multivariate analysis was conducted to test whether correlations existed between working memory performance, trait anxiety, and Iowa gambling task performance. Pearson's correlation indicated there were no significant intervariable correlations, these results are presented below in table 3.

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Table 3

Correlations between trait anxiety, working memory and Iowa gambling task performance

Measure	Trait anxiety	Working memory	Iowa gambling task
Trait anxiety	-	-.09	.014
Working memory	-.09	-	0.015
Iowa gambling task	.014	.015	-

Pearsons R, no correlations were significant

In order to measure whether working memory or trait anxiety related to performance at different stages of the Iowa gambling task, these measures were included in a multivariate analysis with performance at a block level. This analysis revealed no significant correlations and the results of this analysis are available in table 4.

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Table 4

Correlations between Working memory and trait anxiety with Iowa gambling task performance across task execution (block 1-5) and with the operationalised measure of task performance

variable		Working memory	Trait anxiety
Iowa gambling task performance	Operationalised measure of task performance	0.031	.014
	Block 1	-.209	-.086
	Block 2	.130	-.029
	Block 3	.022	.022
	Block 4	-.008	.009
	Block 5	.030	.008

Pearsons R, no correlations were significant

Multiple linear regression examining whether trait anxiety and working memory performance are associated with Iowa gambling task performance

In order to test hypothesis four, a multiple linear regression was used to analyse whether the combination of trait anxiety and complex span task performance predicts Iowa gambling task performance. Shapiro-Wilk test was used to assess normality and it found no significant violations from normality .

The result of the linear regression was nonsignificant $F = 0.014 (3, 62)$, $p = .986$. The multiple correlation coefficient was $R^2 < .001$, indicating that less than 0.1% of the variance was explained by the linear combination of trait anxiety and working memory.

Correlations between working memory performance by task domain and trait anxiety

For hypothesis five, to test whether the separate measures of working memory predicted trait anxiety, a multivariate analysis was conducted to examine correlations between performance on ospan, sspan, rspan, and trait anxiety scores. No significant correlation was found between trait anxiety and ospan ($r = -.15$), rspan ($r = .01$) or sspan ($r = -.02$).

Multiple linear regression examining whether Operation span and trait anxiety correlate with Iowa gambling task performance

To test hypothesis six a linear regression analysis was conducted to examine whether the combination of trait anxiety and operation span performance predicted Iowa gambling task performance. The result of this analysis was non-significant $F = 0.402 (2, 62)$, $p = .671$, the linear combination of trait

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anxiety, and operation span and explained approximately 1% of Iowa gambling task variance ($R^2 = .01$). The intervariable correlations are presented below in table 5.

Table 5

correlations between trait anxiety, operation span performance and Iowa gambling task performance

Measure	Trait anxiety	Operation span	Iowa gambling task
Trait anxiety	-	-.15	.01
Operation span	-.15	-	.11
Iowa gambling task	.01	.11	-

Pearsons R, no correlations were significant

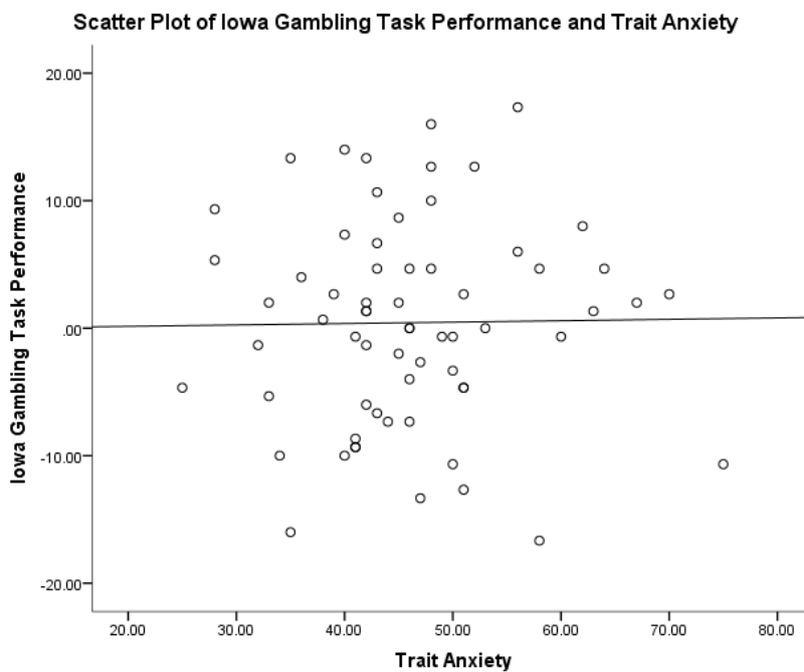


Figure 7

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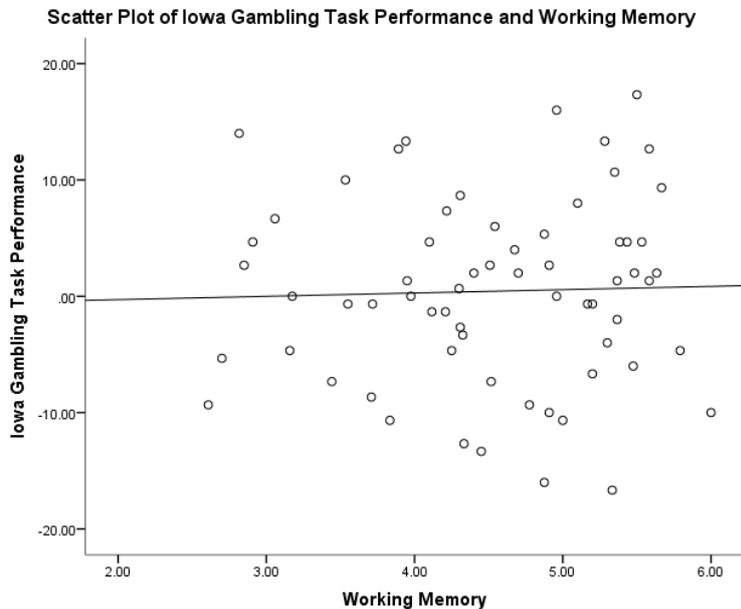


Figure 8

Discussion

The current research aims to examine the correlation between trait anxiety and executive function on complex decision making, six hypotheses were developed to achieve this. Firstly that working memory would correlate with Iowa gambling task performance, secondly that working memory would negatively correlate with trait anxiety, thirdly that trait anxiety would also correlate with Iowa gambling task performance, fourthly that differences in trait anxiety and working memory will predict Iowa gambling task performance. The fifth hypothesis was that the separate working memory span tasks would correlate with trait anxiety, and the sixth was that span and trait anxiety would predict Iowa gambling task performance. The results show no correlations between any of the variables therefore all hypotheses were rejected. The experiment was conducted in order to replicate the

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somewhat consistent relationships between working memory and trait anxiety (Moran, 2016), and also to clarify the inconsistent relationship between working memory and Iowa gambling task (e.g. Toplak, Sorge, Benoit, West, & Stanovich, 2010), and trait anxiety and Iowa gambling task (e.g. Mueller, Nguyen, Ray, & Borkovec, 2010; Zhang, Wang, Zhu, Yu, & Chen, 2015). The results of the current study suggest that working memory, trait anxiety, and complex decision making are not linearly related concepts in this sample. The following section will be separated into subsections that describe how each relationship could be interpreted by the previously discussed theories, and explore explanations for differences between the results of the current experiment and previous research.

Working memory and Complex Decision Making

This experiment's findings that performance on measures of working memory did not correlate with the Iowa gambling task suggests that the capacity to memorise short pieces of information while performing simple abstract manipulations is not related to the propensity to make advantageous decisions in a complex gambling task which is believed by some researchers to be a reflection of real world decision making (Bechara & Damasio 2005). The study hypothesised that working memory would correlate with Iowa gambling task performance because this relationship has been documented in the literature although the majority of studies report there is no relationship (e.g. Farez, Crivelli, Leiguarda, & Correale, 2014; Toplak, Sorge, Benoit, West, & Stanovich, 2010). The results of this experiment suggest that the task is not linearly related to working memory, but unlike initial claims made about the task of a double dissociation between the two concepts (Bechara, Damasio, Tranel, & Anderson 1998), there is strong evidence that working memory is necessary for performance (Bechara & Damasio, 2005). Firstly there is the evidence previously described regarding activity in the dlPFC during task performance (Li, Lu, D'Argembeau, Ng, & Bechara, 2009) and there is

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some support that increasing working memory load reduces performance (e.g. Dretsch & Tipples, 2008; Hinson, Jameson, & Whitney, 2002; Jameson, Hinson, & Whitney, 2004). Therefore these results should be interpreted in terms of an absence of linear relationship between working memory capacity and Iowa gambling task performance, rather than the absence of involvement between working memory and Iowa gambling task performance.

From this perspective it could be posited that too few participants in the current study had a sufficiently low level of working memory to hinder task performance for this difference to be observable. Supporting this perspective, studies that report a relationship between working memory and Iowa gambling task performance compare the groups of high and low level working memory capacity. (Bagneux, Thomassin, Gonthier & Roulin 2013), or have examined groups with psychological disorders (Brown et al., 2015; Farez, Crivelli, Leiguarda, & Correale, 2014), and children (Audusseau & Juhel, 2015). Therefore those samples could have contained a greater representation of low working memory participants compared to the current study (DeLuca, Chelune, Tulsky, Lengsfelder & Chiaravalloti, 2004); Lee and Park, 2005; Raghubar, Barnes and Hecht, 2010). It may be the case these participants were below the working memory threshold necessary to implement the aspects of valuation responsible for task performance variance amongst healthy adults. This means because the current experiment's sample contained participants with average or above average working memory, the influence of working memory was not found.

Dual process model.

The result that individual difference in working memory do not relate to Iowa gambling task performance potentially conflicts with predictions by some dual process models that suggest value is calculated using conscious deliberation and maths (e.g. Konstantinidis & Shanks, 2014, p. 51),.

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Proponents of this position argue working memory is used during the Iowa gambling task to maintain information over time while inhibiting distraction, to consciously perform numerical equations, and to maintain alternative deck information while switching between decks. Therefore the finding that working memory does not relate to Iowa gambling task performance suggests the task is not primarily demanding on working memory. This could be due to a number of factors such as the use of strategies that reduce load on working memory as argued by the fuzzy trace theory (Reyna & Brainerd, 2011). Alternatively it could be that deck value is determined by emotional processes and working memory is necessary only insofar as it facilitates strengthening the association between value and the deck, as argued by the somatic marker hypothesis (Bechara & Damasio, 2005). Alternatively the task could be demanding on working memory, but whether analytical thinking is engaged depends on capacities that are separate from working memory, as argued by a tripartite mind theory of cognitive reflection (Stanovich 2009; Simonovic, Stuppel, Gale, & Sheffield, 2017).

Somatic marker hypothesis.

In contrast the result that working memory does not relate to Iowa gambling task performance is in line with predictions made by the somatic marker hypothesis (Bechara & Damasio, 2005). It posited that working memory is necessary for Iowa gambling task performance but it is not the most demanding aspect of the task, therefore it would not directly relate to individual differences in healthy participants. Specifically the theory suggests that a certain level of working memory is necessary to strengthen the value represented by the decks, but the values are generated using somatic based valuation. This interpretation is in line with evidence described previously that performance on a Iowa gambling task analogue that limits the use of working memory results in

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comparable performance to the standard task (Peatfield, Turnbull, Parkinson, & Intriligator, 2012). Whereas applying a high working memory load (Dretsch & Tipples 2008), or moving deck locations has been found to reduce performance (Pecchinenda, Dretsch, & Chapman, 2006). Further support comes from neural evidence that working memory related neural activation is greater during the task, but does not relate to task performance (Li, Lu, D'Argembeau, Ng, & Bechara, 2009), unlike in areas responsible for emotional value (Lawrence, Jollant, O'Daly, Zelaya & Phillips, 2008). Additionally lesions in areas responsible for emotional value preserves conscious awareness of deck outcomes, but not the capacity to make advantageous decisions or generate related physiological responses (Bechara et al., 1997). In summary there is convincing evidence in support of the role of emotion in determining individual differences in Iowa gambling task performance. In light of previously described evidence the current results suggest working memory likely follows a nonlinear relationship with individual differences in performance because the evidence that working memory is used during the Iowa gambling task appears strong. Although somatic markers appear to be responsible for performance to some extent, the experiment did not test whether this was responsible for performance, and this does not suggest that other factors are not also responsible.

Rational thinking.

Alternatively it could be that working memory has a linear relationship with Iowa gambling task performance, but that this was not reflected by the results of the current research because it is mediated by differences in cognitive reflection. Studies examining the relationship between this concept and Iowa gambling task performance found the measure predicted a large portion of variance (Simonovic et al., 2016; Simonovic, Stuppel, Gale, & Sheffield, 2017). Thus rationality could

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measure the speed of the shift from the previously associated intuition based strategies to one that is cognition based. This factor also pertains to whether both working memory and trait anxiety relate with the Iowa gambling task, and will be discussed in greater detail later in the thesis. However one implication of the importance of cognitive reflection is that the previously reported relationship between working memory and Iowa gambling task performance (Benoit, West, & Stanovich, 2010) might be explained by impaired cognitive reflection for those with low working memory. There is evidence of a relationship between cognitive reflection and working memory, Morsanyi, Busdraghi & Primi (2014) found cognitive reflection was impaired when working memory load was applied, and working memory capacity has been related to susceptibility to a number of decision making biases (Fletcher, Marks and Hine, 2011). It has also been found that decision making biases relate to individual differences in other measures of executive function, although executive functions did not explain a substantial amount of variance (Del Missier, Mäntylä & Bruin, 2011). This implies that after analytical thinking has been engaged, working memory will directly relate to performance differences between participants. The inconsistently reported relationship between working memory and Iowa gambling task performance could to some extent be due to covariance between these indirectly related concepts. In light of this the current results could have failed to find a linear relationship with working memory because the experiment failed to control for rationality, although there is no evidence for this in the current study.

The fuzzy trace theory.

Another perspective is that working memory related to decision making in some participants, but this was mediated by the use of thinking style. The fuzzy trace theory argues that intuition based thinking styles rely less heavily on working memory, whereas analytical thinking does (Reyna & Brainerd,

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2011). Therefore the presence of participants who employ intuitive thinking could have diminished the relationship between working memory and Iowa gambling task performance in the current experiment. Developmental changes in the propensity to employ gist based thinking are argued to occur at a later age than working memory differences (Chick & Reyna, 2012). The age of the current sample is believed to be during the immediately prior to the development of gist based thinking styles (Brainerd and Reyna, 2015). It could be that differences in the speed of development of thinking styles increased thinking styles variance in the current study, while studies that found a relationship had a sample with more homogenous thinking styles that are sensitive to differences in working memory. For example this relationship was found in children who are more likely to employ verbatim reasoning (Audusseau & Juhel, 2015). There is no evidence that this is the case in the current sample however.

Summary.

The current experiment is in line with the majority of research that individual differences in working memory has no relationship with Iowa gambling task performance, this is in contrast to experimental and neurological evidence of this relationship (e.g. Dretsch & Tipples, 2008; Li, Lu, D'Argembeau, Ng, & Bechara, 2009). While the current research found no relationship the evidence that working memory is still necessary for performance is strong, and it is unclear whether this relationship is due to working memory enabling aspects of intuition, strategic thinking or conscious framing. Future research should compare the influence of high, medium, and low working memory on Iowa gambling task performance in relation to differences in cognitive reflection, thinking styles, and somatic responsiveness. In order to measure whether there is a working memory threshold necessary for

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performance, and whether performance differences between working memory capacity are moderated by differences in cognitive reflection or gist based thinking.

Trait Anxiety and Working Memory

Hypothesis two was rejected because trait anxiety did not negatively correlate with working memory, this is in contrast with the majority of studies that tested this relationship (Moran, 2016) including studies utilizing the measures used in the current experiment (e.g. Wright, Dobson & Sears, 2014). Moreover the results also stand in contrast to neuroscientific studies that have found trait, anxiety disorder and depression are correlated with inhibition related neural activity during working memory task performance (Basten, Stelzel & Fiebach, 2012; Fales et al., 2008; Wang et al., 2015). It also conflicts with findings that trait anxiety can be reduced by increasing working memory through training (Mathews, Ridgeway, Cook & Yiend, 2007). Moreover the current results contrast with evidence that experimentally inducing anxiety through physical or social threats reduces working memory (Robinson, Vytal, Cornwell & Grillon, 2013). Additionally the results are contrary to finding that anxiety relates to impairments in other executive functions (Castaneda, Tuulio-Henriksson, Marttunen, Suvisaari & Lönnqvist, 2008). The following section will consider explanations for the failure to find this relationship.

The attentional control theory's interpretation of the results.

Superficially the failure to find a negative correlation between working memory and trait anxiety appears to be incongruent with the attentional control theory (Eysenck et al., 2007), as the theory considers working memory a vital component in regulating emotion. On the other hand proponents

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of the attentional control theory could argue that the task in the current experiment did not provide sufficient working memory load to detect working memory differences between anxious and non-anxious participants (Eysenck & Derakshan, 2011), because high trait anxiety individuals apply greater effort during tasks that require working memory in order to reduce the impairment caused by regulation of worrying thoughts. The theory posits the performance difference between low load and high load working memory tasks highlights differences in working memory efficiency rather than overall working memory capacity. Some evidence that supports this perspective, namely that trait anxiety could be predicted by the interaction between inhibition and working memory (Wright, Dobson & Sears, 2014), that working memory tasks with low working memory load often fail to find a relationship (Moran, 2016). This perspective of how working memory is impacted by anxiety is also supported by studies that show anxiety explains variance in working memory performance, and event related potential markers of executive function after high working memory load is applied, but not under during low levels (Qi et al., 2014). However this relationship has been contested (Stefanopoulou et al., 2014), and the research by Qi et al (2014) used the n-back task which has uncertain validity (Moran 2016). This is also supported by the finding that inhibition related neural activity is greater for participants with high trait anxiety during the distractor periods of working memory tasks (Hoshino 2015). On the other hand most research finds a negative relationship between working memory and trait anxiety even under regular demands (Moran 2016), which is in contrast to predictions by the attentional control theory. Supporting this notion working memory is often related to academic performance (Alloway & Alloway, 2010) and the sample consisted of university students. An implication of this is that the task was unable to highlight the role of additional emotional regulation in high trait anxiety participants because it was not sufficiently demanding. On

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the other hand the attentional control theory fails to explain why working memory relates to trait anxiety in the majority of experiments that use traditional levels of working memory load (Moran 2016).

Population factors.

The results of the current experiment could be explained by research described previously, that found the relationship between trait anxiety and working memory was completely (Chuderski, 2014) or almost entirely (Salthouse, 2012) moderated when controlling for differences in general fluid intelligence. It could be that because the population consisted of students, who are more likely to have a higher level of fluid intelligence (Cliffordson & Gustafsson, 2008), and engage in cognitively demanding activities which are linked to higher general fluid intelligence (Salthouse, 2012). This could mean the relationship between working memory and trait anxiety in the present study was confounded by high intelligence present in the student population used for the study.

One consideration is the relationship between trait anxiety, working memory, and environmental demands on working memory. There is evidence that the relationship between negative affect and working memory in children is mediated by academic test performance and worry (Owens, Stevenson, Hadwin & Norgate, 2012). It could be that trait anxiety is related to working memory when environmental working memory demands exceed the individuals' capacity, and this leads to negative affect by decreasing self-efficacy (Işik, 2012). Low self-efficacy could also explain differences in working memory related activity in trait anxiety, as the inhibition related activity that is impaired in anxiety (Righi, Mecacci & Viggiano, 2009), mediates the positive relationship between self-efficacy and performance on a inhibition task (Themanson & Rosen, 2014). From this perspective differences in working memory efficiency are specific to contexts that incur low self-efficacy, it could be that this

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includes tasks with stimuli that are emotionally neutral but have high attentional demands, such as in education, financial planning, and certain professional obligations. Supporting this, there is evidence that social anxiety relates to greater performance on an n-back analogue that employs emotional images compared to neutral images, whereas the opposite outcome was found in controls (Yoon, Kutz, LeMoult & Joormann, 2016). This suggests different environmental working memory demands could determine the relationship between working memory and trait anxiety by reducing self-efficacy. From this perspective working memory deficits are not inherent to anxiety, and trait anxiety in the current sample was not related to working memory because participants had adequate working memory for environmental demands. Supporting this test anxiety is related to working memory differences (Lee 1999) and is strongly related to trait anxiety (Zettle & Raines, 2000).

Trait Anxiety and Complex Decision Making

The result that trait anxiety does not correlate with Iowa gambling task performance suggests the tendency and sensitivity towards anxiety does not influence complex decision making performance, it calls into question the importance of emotional factors in individual differences in valuation as posited by the somatic marker hypothesis (Bechara & Damasio, 2005), because of the relationship between trait anxiety and somatic responsiveness (de Visser et al., 2010). The following section will first discuss how these results relate to previous research, before exploring the theoretical implications in relation to predictions made by the dual process model, the attentional control theory, the somatic marker hypothesis, and alternative factors.

Previous research.

The study hypothesised that trait anxiety would correlate with complex decision making because there is evidence supporting a positive relationship (e.g. Werner, Duschek, & Schandry, 2009), although there is evidence of a negative relationship (Miu, Heilman, & Houser 2008). However the current results support research by Rocha, Alvarenga, Malloy-Diniz, and Corrêa, (2011) that found no relationship. However the current research was not able to test the results found by Zhang, Wang, Zhu, Yu, and Chen (2015) who reported a nonlinear relationship. They reported that both high and low trait anxiety relate to worse performance, and since these differences would not be measured by the linear analysis used in the current experiment, this could not be tested. These results stand in contrast to the finding that trait anxiety related to greater somatic responsiveness to deck outcomes, and this relates to greater performance (Werner, Duschek, & Schandry, 2009). Additionally the result conflict with evidence of poor real world decision making in anxiety (e.g. Jacka, Mykletun, Berk, Bjelland & Tell, 2011; Leventhal & Zvolensky, 2015), although the validity of the Iowa gambling task as

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a measure of real world decision making has been questioned (Furl, et al., 2009, cited from Furl 2010).

Attentional control theory.

From the perspective that executive function is responsible for lowa gambling task performance, this experiments' result is contrary to reasoning that higher trait anxiety would relate to worse complex decision making performance because intrusive thoughts hinder the conscious calculation of choice outcomes, and reduces the capacity to inhibit high loss high reward options (Eysenck et al, 2007).

From the attentional control theory's perspective, only working memory efficiency is impaired by anxiety, and as described previously there is some evidence for this position (Qi et al., 2014; Moran 2016 Hoshino 2015). From one perspective this indicates the task does not have high working memory demands. This position is supported by evidence that non-executive cognitive processes explain task variance. The finding that trait anxiety does not relate to lowa gambling task performance suggests working memory efficiency does not contribute to task performance. This perspective explains the findings that working memory is related to anxiety, yet the anxiety is sometimes related to lowa gambling task performance positive (e.g. Werner, Duschek, & Schandry 2009). On the other hand it should be considered that the current sample may have a higher than average working memory (Alloway & Alloway, 2010), and this could have concealed this relationship by not testing working memory efficiency.

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Somatic marker hypothesis.

The somatic marker hypothesis could be interpreted as predicting a number of directions for the relationship between trait anxiety and complex decision making. Nguyen, Ray, and Borkovec (2010) and others (e.g. Werner, Duschek, and Schandry, 2009) argue that in healthy participants, lowa gambling task performance positively relates to measures of anxiety as these measures are positively associated with somatic responsiveness to decision outcomes. lowa gambling task performance has been positively related to a number of physiological markers including anticipatory skin responses (Werner, Duschek, & Schandry, 2009), heartrate variability (Drucaroff et al., 2011) and pupillary response (Simonovic, Stupple, Gale, & Sheffield, 2017). Similarly there is evidence that trait anxiety relates to greater anticipatory skin response during the lowa gambling task (Werner, Duschek, & Schandry, 2009). On the other hand Miu, Heilman, and Houser (2008) found high trait anxiety predicted poorer lowa gambling task performance than low trait anxiety, they also found higher anticipatory skin response variability in participants with high trait anxiety, but this did not relate to performance. Werner, Duschek, and Schandry (2009) argued that the absence of relationship was due to comparing participants with extreme high to low trait anxiety scores, supporting this Zhang, Wang, Zhu, Yu, and Chen (2015) found high and low trait anxiety related to poorer performance compared to medium trait anxiety. The current sample had greater variability and higher trait anxiety scores on average ($M=46.09$, $SD=9.87$) compared with the study by Werner, Duschek, and Schandry, (2009) ($M=34.9$, $SD=5.41$) which had a similar sample size ($n=64$) and age demographic ($M=23.47$). It could be the case that the current study found no relationship between trait anxiety and lowa gambling task performance due to high or low levels of trait anxiety, that relate to poorer performance. This could be due to affective information overriding the utilisation of cues. They cite Leon and Revelle (1985)

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who found ego threat resulted in faster response time and reduced accuracy in high trait anxiety participants on an analogical reasoning task. Revelle (1985) argued trait anxiety leads to poor task related cue recognition during stress. Miu, Heilman, and Houser (2008) and Werner, Duschek, and Schandry, (2009) suggest this could be due to task unrelated stress which has been related to reduced performance (Preston, Buchanan, Stansfield & Bechara, 2007). Miu, Heilman, and Houser (2008) suggest this could be due to reduced task attention through emotion related distraction, or due to differences in processing emotional information prior to attention, which is supported by differences in pre conscious activation in the amygdala in people high trait anxiety (Etkin et al., 2004).

It could also be argued from the somatic marker hypothesis' perspective that worse Iowa gambling task performance found in high and low levels of anxiety could be explained by the effect of 'background' somatic states on perception of value (Bechara & Damasio, 2005). There is evidence to suggest trait anxiety is related to both anxiety and depression, and that it is more accurately conceptualised as a predisposition towards negative affect (Balsamo et al., 2013), meaning high trait anxiety and low trait anxiety could relate to negative and positive background somatic states respectively, which would cause the decks to be valued excessively positively or negatively.

Supporting this depression and anxiety has been related to more negative interpretation of ambiguous stimuli (Blanchette & Richards, 2010), and training a more neutral interpretation of events has been found to reduce trait anxiety (Mathews, Ridgeway, Cook & Yiend, 2007). Moreover, high trait anxiety was associated with fearful face attentional bias, and this related to greater emotion related (N1), and less executive function related (N2) electrophysiological activity (Penf, Yang & Luo, 2013). This suggests an overly negative interpretation of stimuli could impair decision making at higher levels of anxiety. Regarding the current experiment this means anxiety failed to find a linear

relationship because of emotional impairments at high levels of anxiety, while greater somatic markers improve performance at lower levels.

Working memory, trait anxiety and lowa gambling task performance

Hypothesis four is rejected as the combination of trait anxiety and working memory did not correlate with complex decision making. This is contrary to the rationale that trait anxiety is related to a number of behaviours believed to contribute to lowa gambling task performance such as loss aversion (Zinbarg & Mohlman, 1998) and somatic responsiveness (Werner, Duschek, and Schandry, 2009), and that working memory capacity is necessary to inhibit goal irrelevant stimuli, manipulate abstract information, and exercise temporal discounting during the task (Evans & Stanovich, 2013). Moreover it was argued that these factors would independently correlate with lowa gambling task performance as trait anxiety and working memory negatively relate to one another (Moran 2016), meaning together they would explain a moderate amount lowa gambling task performance variance.

Hypothesis six is also rejected as operation span and trait anxiety did not predict lowa gambling task performance. This is contrary to the rationale that a measure of working memory that requires mathematics would relate to the calculation of deck outcomes, because researchers have argued that they involve the same domain knowledge. This section will consider positions that explain why the combination of trait anxiety and working memory failed to relate to lowa gambling task performance. Specifically this section will discuss how differences in working memory and trait anxiety could be compensated for by learning strategies. It will also consider the role of so called rational decision making in lowa gambling task performance. Finally it will discuss whether lowa gambling task is a predictor of the real world decision making behaviours associated with trait anxiety.

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Thinking styles and biases.

Toplak, Sorge, Benoit, West, and Stanovich (2010) suggest intelligence has little impact on the capacity to make decisions when the task requirements are ambiguous, because this relates to an individual's level of rationality. Citing Stanovich (2009) they argue rationality is separate from traditionally defined intelligence and is responsible for beliefs, long term goals and general knowledge. Critically, they also argue that although rationality is correlated with intelligence this system is not measured by typical tests of executive function (Toplak, West & Stanovich, 2011), which they refer to as the algorithmic mind. They posit the rational system has hierarchical control over what aspect of the algorithmic system is implemented, meaning that the capacity to make advantageous choices in the Iowa gambling task depends to a large extent on how effectively the rational system can detect the need to override automatic behaviour, and induce analytical thinking. This means trait anxiety related working memory efficiency deficits, and typical measures of working memory have little or no correlation with Iowa gambling task performance, because whether analytical thinking occurs is determined by differences in the rational system.

Simonovic, Stuppel, Gale, and Sheffield, (2017) suggest that somatic markers could be used as value markers for analytical thinking. This suggests that while emotional cues are involved in the perception of deck value, whether these faculties are employed is not determined by these emotional attributes. Similar to their description of the influence of working memory, this means the general strength of somatic markers found in trait anxiety during Iowa gambling task performance (e.g. Werner, Duschek, & Schandry, 2009), only explain variation when rational thinking facilitates analytical thinking. From this perspective the advantageous influence of both somatic markers and working memory is dependant on whether analytical thinking is engaged. This would explain the result that trait anxiety

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but not working memory related to task performance in children (Kirsch & Windmann, 2009), who perform worse in measures of rationality compared to adolescents and adults (Toplak, West & Stanovich, 2014). This suggests trait anxiety relates to Iowa gambling task performance in the absence of analytical thinking, meaning intuitive avoidance to losses occurs before conscious awareness, but the application of analytical thinking disrupts this influence. However this position conflicts with the perspective of the fuzzy trace theory, which argues that verbatim based thinking relates to greater decision making, and this thinking style is found in children (Reyna and Brainerd, 2011). Although it could be argued children lack sufficient working memory to calculate the Iowa gambling tasks contingencies (Cliffordson & Gustafsson, 2008).

The importance of rational thinking suggests differences in the susceptibility to failures on specific types of rationality could explain the inconstant relationship between trait anxiety and the Iowa gambling task. The rational system is comprised of several components that are related but separate constructs, such as resistance to negative or positive framing, gamblers fallacy (Toplak, West & Stanovich, 2011), or the acceptance of pseudo profound nonsense (Pennycook, 2016; Pennycook, Cheyne, Barr, Koehler, & Fugelsang, 2015). The influence of framing has been found to differ between individuals based on context and task domain (Zhen & Yu, 2016). Negative perceptual bias has been suggested to improve performance in the Iowa gambling task by Mueller, Nguyen, Ray and Borkovec, (2010). Negative framing effects on gambling decision making has been found to be greater in trait anxiety, even after controlling for risk (Gu et al., 2017), and greater loss related neural activity has also been found (e.g. Gehring, Coles, Meyer, & Donchin, 1995; Zhen & Yu, 2016), which suggest greater sensitivity towards negative value in high trait anxiety. In relation to the Iowa gambling task this means participants with a negative bias could be more likely to reframe a deck as bad following a loss.

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Moreover this occurs in the absence of analytical thinking, which suggests the relationship between anxiety and lowa gambling task performance is mediated by the use of an intuitive thinking style.

A lower representation of participants with a negative cognitive style could explain the failure to find a relationship with trait anxiety and decision making in the current experiment. There is non-experimental evidence that negative value attributions relate to poor academic performance (Fries, Schmid & Hofer, 2007), meaning the current studies population of students could have unrepresented this cognitive style compared to prisoners, (Schmitt, Brinkley, & Newman, 1999), individuals with affective disorder (Mueller, Nguyen, Ray, & Borkovec, 2010), and children (Kirsch, & Windmann, 2009). However Werner, Duschek, and Schandry (2009) found trait anxiety related to lowa gambling task performance in a university population, therefore there is no clear explanation for this conflict. It could be that because the sample consisted of university students who have experience in maintaining focus over prolonged periods of time on difficult learning tasks, students with lower working memory or high trait anxiety engaged learning strategies that compensated for their cognitive and emotional limitations. For example participants with high trait anxiety could engage in stress management exercises, while a participant with lower working memory could engage in greater rehearsal of choice outcomes. There is some evidence that differences in education relate to differences in the use of compensatory learning strategies. Kirby, Silvestri, Allingham, Parrila and La Fave (2008) found university students with dyslexia, a reading disorder found to be related to working memory deficits (Beneventi, Tønnessen, Ersland & Hugdahl, 2010), typically engage in more deep learning strategies, but that this relationship was not present in vocational college students. Furthermore the present sample consisted primarily of psychology students (n=59) who could be more aware of their own cognitive or emotional dispositions, and more inclined to engage in

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compensatory strategies. To summarise population differences in domain related reflective thinking could mediate the relationship with Iowa gambling task performance for both working memory, and trait anxiety, and this could occur through differences in rational thinking mediating the use of analytical thinking and emotional cues.

Environmental validity.

The finding that both working memory and trait anxiety do not relate to Iowa gambling task performance questions the environmental validity of the task. The task was originally developed to measure decision making deficits in patients with lesions in the vmPFC, however previous research has found that the relationship between performance and real world decision making in healthy participants is small (Furl 2010) or negative (Furl, et al., 2009, cited from Furl 2010). On the other hand there is strong evidence that task performance relates to prolonged substance abuse, (Verdejo-Garcia, Bechara, Recknor & Perez-Garcia, 2006), criminality (Yechiam et al., 2008), and pathological gambling (Goudriaan, Oosterlaan, de Beurs & van den Brink, 2005). This again suggests that differences in Iowa gambling task performance are only sensitive to more profound cognitive impairments. It may be that individual difference associated with trait anxiety and working memory did not impact performance because the task did not sufficiently reflect real world rewards or temporal discounting demands. For example, differences in impulsivity (Eysenck et al, 2007), or loss aversion may not have been measured because the rewards and losses were insufficient to entice or repel healthy participants. Alternatively according to the fuzzy trace theory, the propensity towards gist based thinking is an adaptive developmental change because it provides strong emotional cues that prevent risky behaviour (Reyna and Brainerd, 2011). This means that risky decision makers that rely

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on verbatim based thinking could be tempted by high risk high reward decks at a later stage in the task, but this effect would be less visible because they are more likely to learn deck outcomes faster. This suggests the use of gist based thinking mediates the relationship between working memory and trait anxiety.

Limitations.

The study contained a number of limitations, firstly it failed to control for clinically diagnosed psychological disorders, which have been found to relate to all the measures used in this study (e.g. (Cella, Dymond & Cooper, 2010; Haaland & Landrø, 2007; Owens, Koster & Derakshan, 2013; Soraggi-Frez, Santos, Albuquerque & Malloy-Diniz, 2017). This potentially explains the greater variation in trait anxiety scores found in this experiment compared to previous research using a similar sample population (Pajkossy, & Racsmány 2014; Werner, Duschek, & Schandry 2009). It may be that disorder specific deficits could have concealed the positive relationship between trait anxiety and Iowa gambling task performance in healthy controls. Secondly the study was slightly underpowered to measure a moderate effect size. However previous research using a similar sample size has found that trait anxiety (Werner, Duschek, & Schandry 2009), and working memory (Brown et al., 2015) have related to gambling task performance. Most research has found each measure relate to a small amount of Iowa gambling task performance. It was posited that the two variables would predict a moderate amount of variance when combined, however it could be the case that either trait anxiety or working memory relate to a small amount of performance variance which the current experiment was unable to detect. Another limitation was the method of sampling used for this study.

Participation in the experiment was part of a mandatory course requirement for the majority of the sample (n=59) whereas the experiment by Werner, Duschek, and Schandry (2009) that found trait

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anxiety related to Iowa gambling task performance in students, rewarded participants with 20 euros for participation. Therefore this conflict may be due to differences in mood. Positive mood has been shown to increase association learning flexibility (Sacharin 2009), and reversal learning is necessary due to initial high rewards from the bad decks (e.g. Pasion et al., 2017), and negative mood facilitates intuitive thinking (Pretz, Tetz & Kaufman, 2010). Moreover the mandatory nature of recruitment may have even framed lower controllability, which has been found to reduce effortful subjective value based decision making (Sedek, Kofta & Tyszka, 1993), which is believed to be induced by rationality in an ambiguous context (Simonovic, Stuppel, Gale, & Sheffield, 2017). This could also explain the low average scores, on the final deck participants made 0.19 more advantageous choices than disadvantageous ones. Additionally because the sample only contained young adults it could be the case that developmental differences influence the relationship working memory and trait anxiety have with Iowa gambling task performance (Chick & Reyna, 2012). Lastly the study failed to examine whether Iowa gambling task performance could have a nonlinear relationship with trait anxiety and working memory. Zhang, Wang, Zhu, Yu, and Chen (2015) has found that trait anxiety and Iowa gambling task performance have a nonlinear relationship, and working memory appears to be related to Iowa gambling task performance at lower levels. Bagnoux, Thomassin, Gonthier and Roulin (2013) found that low levels of working memory related to worse performance compared to high levels, and studies that load working memory, and studies that load working memory reduce performance (e.g. Dretsch & Tipples, 2008), however it is unclear whether high or medium levels of working memory have a different impact on performance. Additionally the somatic marker hypothesis argues that working memory is necessary only insofar as it facilitates other processes as described previously

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(Bechara & Damasio, 2005), therefore a high level of working memory would not result in greater Iowa gambling task performance than medium working memory.

Conclusion

The current study failed to find a relationship between working memory, trait anxiety, and complex decision making in young adults, and also the relationship between a working memory measurement that tests resistance to mathematical distraction, trait anxiety, and complex decision making. These results highlight the multifaceted nature of these variables. This section will conclude by discussing these findings in light of previous research. The evidence suggests that while working memory is necessary for mathematical calculation, during an ambiguous task such as the Iowa gambling task it relates to relatively little or no performance in adult participants. Similarly, trait anxiety relates to little or no difference in performance even though it is related to greater somatic responsiveness found to facilitate cue detection. Although the current study failed to linearly correlate these concepts, the evidence suggests both anxiety and working memory relate to complex decision making but this relationship remains unknown. Indeed, this thesis has considered evidence that suggests low working memory can impact performance at multiple stages of decision making, that working memory is responsible for the mathematical calculation of deck outcomes, in strengthening the value that is associated with a deck, and inhibiting the impulse to choose a high risk high reward deck. However, there is strong evidence of non-executive based processes determining the involvement of working memory in complex decision making performance, namely, cognitive style. Finally, it is unclear whether low working memory demands are required for performance once cognitive reflection has

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induced analytical thinking. Therefore it is likely that the current result that working memory does not relate to Iowa gambling task performance in a linear direction in healthy adults is accurate.

The failure to find a linear relationship between trait anxiety and Iowa gambling task performance in the current study cannot test the position that this relationship follows an inverted u shaped curve. Several mechanisms that explain this relationship are both likely to influence performance, and are not necessarily incompatible. Firstly trait anxiety could relate to task performance in healthy people due to greater cue sensitivity. Secondly people with low working memory, or with an inclination towards intuitive decision making could benefit from a susceptibility to negative framing bias when interpreting deck outcomes. Thirdly high levels of anxiety could impair executive function, and reduce performance by impairing outcome calculations. Finally that trait anxiety relates to a negative interpretations of outcomes, which induces greater switching behaviour, and causes worse performance.

The research was unable to clarify the relationship between working memory and trait anxiety by looking at domain specific variance because no relationship was found. The failure to find a relationship between any measure of working memory and trait anxiety was surprising, since there is strong evidence of a relationship (Moran 2016), although nonsignificant results have been reported.

The result is likely due to greater intelligence in the study's population and the relatively low environmental demands on working memory and a relatively high perception of self-efficacy,

In summary there are several components that determine the involvement of trait anxiety and working memory in complex decision making, and a linear relationship between these variables is improbable. Future research that examines this relationship should consider a variety of factors due

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to the complex nature of the behaviour. To gain a more complete understanding it would be profitable to measure how gist based thinking, rational thinking, somatic responsiveness, working memory, and trait anxiety interact to predicting Iowa gambling task performance. This thesis has considered evidence that these variables are interconnected, and that they potentially interact. Moreover research should consider examining the relationship between verbatim, or analytical thinking during the Iowa gambling task using an EEG. It would be informative to test whether these thinking styles relates to executive function related activity, and how this relates to differences in trait anxiety and working memory. Additionally future research should compare a broad range of age groups in order to control for age related differences in decision making style due to differences in cognitive reflection, and decision making style. The relationship between trait anxiety and working memory should also be considered in relation to the number of environmental demands on working memory, and how this relate to self-efficacy. Finally there is strong evidence that the relationship between working memory, trait anxiety, and Iowa gambling task performance is non-linear, future research examining this relationship should categorise the sample into high, medium, and low categories of working memory and trait anxiety.

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