A New Cognitive Paradigm for Measuring Attentional Control and Attentional Bias in Children and Adults

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Abstract

Biases in attentional processing of threat are a key factor in anxiety disorders (Bar-Haim et al., 2011). Emerging research suggests that prefrontal control mechanisms, such as attentional control, may moderate this attentional bias toward threat in individuals with anxiety (Eysenck et al., 2007). However, the absence of reliable behavioural measures for attentional control and attentional bias, alongside limited sensitivity to developmental changes, has limited progress in understanding their relationship with anxiety.

The aim of this thesis was to address these gaps by developing a novel paradigm adapted from Astle et al.'s (2014) Visual Short-Term Memory (VSTM) task. This paradigm integrates distractor stimuli to assess attentional control and varies the threat level of these distractors to measure attentional bias toward threat. Participants included 115 adults and 15 children (aged 5–14 years).

Mixed-model analyses of trial-by-trial performance revealed that adults with higher levels of anxiety did not exhibit deficits in attentional control, challenging prior findings from subjective self-report measures of attentional control (Shi et al., 2019). Interestingly, adults with higher anxiety improved their performance in trials involving threatening distractors, suggesting an attentional avoidance of, rather than a bias toward, threat. Conversely, children with higher anxiety demonstrated impaired attentional control but did not exhibit significant differences in attentional bias relative to their less anxious peers.

These findings suggest that attentional biases in adults with higher anxiety may stem from adaptive performance strategies rather than underlying prefrontal control deficits. In children, delays in attentional control development may critically influence these strategies. Theoretical implications, methodological advancements, and potential clinical applications are discussed alongside study limitations and future directions.

Statement of Originality

I hereby certify that this thesis contains no material previously submitted for any degree or diploma at any university without proper acknowledgment. To the best of my knowledge, it includes no material previously published or authored by another person, except where appropriate references have been provided in the text.

Johannes Heese, 29/11/2024.

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Chapter 1

Introduction

Biases in information processing are thought to play a pivotal role in the development and maintenance of anxiety and mood disorders (Clark & McManus, 2002). One prominent bias involves the automatic and disproportionate attention towards threat-related stimuli, which is commonly observed among individuals with elevated levels of trait anxiety. Anxious individuals tend to exhibit an attentional bias toward threatening and emotionally salient stimuli (Bar-Haim et al., 2011). Specifically, their attention is more readily captured by threatening stimuli, and they experience greater difficulty disengaging from these stimuli.

Recent meta-analytic data suggest that the relationship between attentional bias toward threat and anxiety is moderated by age (Dudeney et al., 2015). Young children generally display an attentional bias towards threat, although through middle childhood differences emerge based on anxiety level. Between the ages of 7 and 12 years there appears to be a critical shift in development, impacting the way children with anxiety attend towards threat.

Eysenck's Attentional Control Theory (ACT; Eysenck et al., 2007) posits that attentional bias in individuals with anxiety results from diminished top-down attentional control. Attentional control refers to the ability to flexibly direct and shift attention in line with current goals (Muris et al., 2008). According to ACT, anxiety disrupts the functioning of the goal-directed attentional system, increasing reliance on stimulus-driven attentional processes. Consequently, anxious individuals struggle to sustain attention towards task-relevant information, as their attention is frequently captured by rumination and potentially threatening distractors. This dynamic perpetuates the maintenance of anxiety and related disorders.

Children with high attentional control ability may be able to counteract attentional bias towards threat, safeguarding against the development of emotional disorders such as anxiety. Accordingly, the development of attentional bias towards threat in anxiety is moderated by these top-down attentional control abilities. However, an alternative explanation is that attentional bias towards threat reflects a heightened salience of these stimuli, which overwhelms otherwise intact attentional control abilities. A third possibility is that differences in stimulus-driven attention to threat and differences in goal-directed attentional control are independent processes that can both influence anxiety.

It is critical to understand the causal role of these two cognitive processes in the development of anxiety disorders in childhood and adolescence in order to design effective interventions. Despite the importance of attentional control and attentional bias in anxiety, the literature examining the relationship between the two remains limited. Derryberry and Reed (2002) found that it was only for children who self-reported high levels of attentional control that there was a strong relationship between attention biases and anxiety. Findings from neuroimaging studies show that individuals with anxiety display deficient recruitment of prefrontal control mechanisms as well as increased amygdaloid hyper-responsiveness to threat (Bishop, 2007). Further, researchers have found evidence that attentional control ability moderates both attentional bias and efficacy of interventions that manipulate attentional bias (Attentional Bias Modification treatment [ABM]; Amir et al., 2016; Salemink & Wiers, 2012). Although this research provides a compelling argument for the role of "top down" attentional control deficits in anxiety, they have major limitations that can only be addressed by new methodologies.

Past research has not adequately measured attentional control. Studies have relied upon self-report measures such as the attentional control scale (ACS) when examining the interaction between attentional control and attentional bias. Research from Todd and colleagues (2022) has shown that ACS measures do not correlate with behavioural measures of attentional control, suggesting that self-monitoring of this cognitive process is inadequate. Tasks such as the emotional anti-saccade task have the potential to be used to measure both attentional control and attentional bias behaviourally (Chen et al., 2015). Although, research on test-retest reliability for the use of the anti-saccade task in children concluded that this task is not useful for predictive studies in children (Klein & Fischer, 2005). For this reason, new methodology is required to understand the relationship between attentional control, attentional bias and anxiety. Methodology that measures both constructs behaviourally and is sensitive to critical developmental changes.

To advance research on cognitive changes in middle childhood, we have adapted a visual short-term memory task (VSTM; Awh & Vogel, 2006; Astle et al., 2014) by incorporating distractors with varying levels of threat. The task involves a memory array of target and distractor objects, followed by a blank retention interval and a test array where participants judge if target objects have changed. In distractor trials, participants focus on designated target items while ignoring distractors, whilst “no-distractor” trials include only target items. Conflict trials, where distractors change but targets do not (or vice versa), test attentional control, as distractors introduce ambiguity in required response. Individuals with high attentional control show smaller performance deficits in these trials compared to non-conflict trials, while those with poor attentional control struggle more. Distractor images, sourced from the International Affective Picture System (IAPS; Bradley & Lang, 2007), include 20 images split evenly between neutral and threatening categories. Comparing performance across neutral and threatening distractors allows us to examine whether deficits in attentional control are general or anxiety-related, particularly for threatening stimuli.

Crucially, VSTM tasks are sensitive to developmental changes from middle childhood into adulthood, and our modifications enable the concurrent measurement of attentional control and attentional bias. In this study, we recruit both adult and child participants, allowing us to compare performance patterns across age groups. This dual-sample approach serves to validate the robustness of our methodology in assessing attentional control across development while also advancing our understanding of its trajectory over time.

Chapter 2

Literature Review

Anxiety disorders are among the most prevalent and debilitating causes of disease in modern society, with the Institute for Health Metrics and Evaluation (2019) estimating as many as 301 million people are affected worldwide. Anxiety is characterised by fear and worry that is both intense and excessive. Whilst a normative function underlying fear is the facilitation and detection of threat in our environment, allowing for appropriate responding towards these stressors, it is theorised that maladaptation of this response towards threat may facilitate the excessive and intense fear and worry associated with anxiety (Beck, 1976; Eysenck, 1992; Mathews, 1990; Mathews & MacLeod, 2002; Williams et al., 1988). Understanding the underlying mechanisms behind these maladaptive responses to environmental stimuli is central to the development of treatment for anxiety.

This review examines the role of attentional biases in anxiety, emphasising how attentional control—an individual's capacity to regulate and direct their attention—may moderate the relationship between these constructs. Additionally, we explore the developmental trajectory of these constructs, addressing methodological limitations in assessing them during the most critical developmental stages. Finally, we argue that methodologies from the adjacent field of working memory provide a framework for measuring attentional control and attentional bias that overcomes these limitations, offering new insights into the roles of these constructs play in anxiety.

Attentional Bias in Anxiety

Research over the past 30 years has targeted the role that cognition plays in the development and maintenance of anxiety. Beck and Clark’s cognitive motivational model (Beck & Clark, 1988) proposes that cognitive processing is largely influenced by schemas, which guide how information is attended to, interpreted, and remembered. Cognitive bias in anxiety is believed to result from an overactivation of the primal threat mode, coupled with strategic processing tendencies that prioritize threat-related stimuli. In this way anxiety is developed and maintained through an over attention towards threat, reinforcing the belief that their environment is unsafe. This creates a cognitive loop where individuals with anxiety interpret neutral situations as threatening, further exacerbating anxiety.

A range of empirical evidence supports the existence of attentional bias toward threat in anxious adults (e.g., MacLeod et al., 1986; Mogg et al., 1992; Bar-Haim et al., 2007). This bias has been observed in both clinically anxious vs. non-anxious populations (Dudeney et al., 2015; Mogg et al., 1992) and in individuals with high vs. low trait anxiety (Grafton & MacLeod, 2014; Kret et al., 2017). Attentional bias toward threat is often conceptualized as comprising three distinct components: facilitated attention to threat, delayed disengagement from threat, and attentional avoidance of threat, each representing different stages of attentional processing, particularly in relation to anxiety. While there is general evidence for an overall attentional bias toward threat in anxious adults, studies examining these subcomponents have produced conflicting findings. These inconsistencies suggest that the nature of this bias is more complex than previously understood.

1. Facilitated Attention to Threat:

Facilitated attention refers to the rapid initial orientation towards threatening stimuli. Koster et al. (2006) demonstrated that individuals with high trait anxiety (HTA) showed facilitated attention towards highly threatening stimuli, particularly when displayed for short durations, such as 100 ms. This tendency for facilitated attention has been supported by research using the dot-probe paradigm, which allows for the separation of facilitated attention from difficulties in disengagement. For instance, Koster and colleagues (2004a, 2004b) found evidence for facilitated attention towards supraliminally presented threat-related stimuli. However, some studies using the spatial cueing task have not consistently shown facilitated attention effects. For example, Amir et al. (2003) and Fox et al. (2001) failed to observe facilitated attention in their spatial cueing studies, indicating potential variability in findings depending on the task and experimental setup.

2. Delayed Disengagement from Threat:

Delayed disengagement refers to the difficulty individuals experience in shifting attention away from threatening stimuli once it has been captured. This component has been consistently demonstrated using the spatial cueing task, where anxious individuals show prolonged attention on threatening cues before being able to move their attention elsewhere (Amir et al., 2003; Fox et al., 2001; Koster et al., 2006; Cisler & Koster, 2010). The difficulty in disengaging from threat may contribute to the persistence of anxious thoughts, as attention remains anchored to potentially negative information.

3. Attentional Avoidance of Threat:

Attentional avoidance is observed when anxious individuals shift their attention away from threatening stimuli after an initial period of engagement. Studies suggest that, at longer stimulus presentation times (typically greater than 1000 ms), anxious individuals display a reverse congruency effect in the dot-probe paradigm, indicative of attentional avoidance (Koster et al., 2005). Furthermore, research examining eye movements has provided additional support for attentional avoidance. For example, Garner et al. (2006) and Calvo and Avero (2005) found that anxious participants, after initially fixating on threat-related stimuli, subsequently looked away. Pflugshaupt et al. (2005) demonstrated this effect in spider-phobic individuals, who exhibited rapid initial eye movements towards spider stimuli followed by avoidance, as indicated by eye movement fixations away from the threat. This pattern of avoidance may function as a coping mechanism that reduces anxiety by limiting exposure to threatening stimuli.

Theoretical Models of Attentional Bias

Several proposed models attempt to explain the relationship between attentional bias and anxiety, the present review will summarise some of the key models detailing this relationship. Models of attentional bias towards threat can be split into two schools, cognitive theories and attentional theories. Cognitive theories emphasize the influence of conscious cognitive processes in shaping attentional bias, suggesting that deliberate processing guides this tendency. In contrast, attentional theories propose that less conscious, involuntary mechanisms underlie the allocation of resources, driving this bias. These models seek to explain the previously mentioned subcomponents of attentional biases. Cognitive models, such as Beck and Clark's (1997) model, emphasize strategic threat elaboration mechanisms, whereas attentional theories focus on deficits in attentional control (e.g., Eysenck et al., 2007) or on guided threat evaluation systems (e.g., Bar-Haim et al., 2007).

Cognitive Theories

Beck and Clark's Cognitive Model (1997).

Beck and Clark propose that cognitive processing is largely influenced by schemas, which guide how information is attended to, interpreted, and remembered. Their three-stage schema-based information processing model of anxiety includes: (a) initial registration of threat, (b) activation of a primal threat mode, and (c) secondary activation of more elaborative and reflective modes of thinking. Cognitive bias in anxiety is believed to result from an overactivation of the primal threat mode, coupled with strategic processing tendencies that prioritize threat-related stimuli. While the model emphasizes threat processing in anxiety, it does not fully explain how these cognitive mechanisms might evolve or change over different stages of development, such as during adolescence or middle childhood.

Mogg and Bradley's Cognitive Motivational Model (1998).

According to Mogg and Bradley's cognitive-motivational model (1998), anxiety influences the conscious appraisal of threat, leading high trait-anxious individuals to perceive relatively innocuous stimuli as threatening. Attentional bias towards threat emerges from this heightened sensitivity, rather than from a fundamental bias in how attention is directed. In essence, the model suggests that everyone exhibits heightened attention to stimuli they perceive as threatening, but anxious individuals interpret a wider range of stimuli as potential threats. One difficulty with this theory is that there is little evidence for an overly sensitive valence evaluation mechanism apart from the observations the mechanism was used to explain (Cisler & Koster, 2010).

Attentional Theories

Williams, Watts, MacLeod and Mathews (1988) Model.

Attentional theories, such as those proposed by Williams et al. (1988), suggest that anxious individuals exhibit an initial attentional bias toward threatening stimuli during early, automatic stages of processing. However, in later, more strategic stages, they tend to shift their attention away from the threat. This theory provides insight into how attentional biases contribute to both the development and maintenance of anxiety. The early automatic orientation towards threat intensifies anxiety, while the subsequent avoidance prevents the individual from engaging in elaborative cognitive processes that could reduce the perceived intensity of the threat. Williams et al. argue that highly anxious individuals are prone to an attentional bias toward threatening stimuli, while low-anxious individuals are more likely to disregard threatening information. Mogg and Bradley (1998) challenge this idea, suggesting it is unlikely that low-anxious individuals would fail to attend to severe threats. Supporting this, Wilson and MacLeod (2003) demonstrated that low-anxious individuals indeed exhibit attentional biases for severely threatening stimuli, though not for moderately threatening ones.

Bar-Haim et al. (2007).

Bar-Haim et al suggest a multidimensional model of the attentive system responsible for threat evaluation. This model is broken into three distinct phases; 1) pre attentive threat evaluation system that evaluates the environmental stimuli 2) threatening stimuli feed into a resource allocation system and elicits a physiological arousal and allocation of cognitive resources 3) a guided threat evaluation system then assesses the context of the threat and assess available coping resources. If the guided threat evaluation system determines a stimulus to have low threat significance, the pre-attentive system's input is overridden by the goal-directed engagement system. Alternately if a stimulus is deemed of high threat significance, attention is maintained on the threat.

Eysenck and Colleague's Attentional Control Theory (2007).

According to Eysenck's attentional control theory, anxiety impairs the ability for individuals to control their attention. More specifically, it impairs the ability to inhibit and shift attention. It is proposed that the development of anxiety is shaped by deficits in attentional control, as individuals with lower attentional control struggle to disengage from threatening stimuli and intrusive thoughts. This prolonged fixation may contribute to both the onset and maintenance of anxiety. A recent meta-analysis compiling results from 58 studies examining attentional control and anxiety found support for this model of anxieties relationship with attentional control (Shi et al., 2019). Overall, anxiety was associated with significant deficits in attentional control ability, specifically in anxious individuals' ability to inhibit and shift their attention, but not in updating. Further, evidence suggested that age moderated this difference in attentional control ability, highlighting the potential developmental role attentional control could play in anxiety development.

Summary of Models:

Most models of attentional bias in anxiety propose that anxiety heightens vigilance or facilitates attention towards threat. For instance, Beck and Clark (1997) and Eysenck et al. (2007) both address difficulties in disengaging attention from threatening stimuli, while only Williams et al. (1988) includes a component of attentional avoidance in response to threat.

Regarding the mechanisms that mediate attentional biases, most models attribute these biases to a maladaptation of a threat detection system. In contrast, Eysenck's Attentional Control Theory (ACT; Eysenck et al., 2007) suggests that the threat detection system remains intact, but attentional biases arise from deficiencies in attentional control. Eysenck's theory specifically links difficulty in disengaging from threat to disruptions in attentional control, whereas Bar-Haim et al. (2007) attribute this difficulty to a guided threat evaluation system.

Experimental Paradigms Examining Attentional Bias and Anxiety

Four primary experimental paradigms are used to examine attentional bias in anxiety: the emotional Stroop task, emotional spatial cueing task, dot-probe paradigm, and emotional anti-saccade task. The consistent finding of anxiety-linked attentional bias toward threat across these paradigms underscores the generalizability of this phenomenon.

The Emotional Stroop Task (Williams et al., 1996).

The emotional Stroop task is a modified version of the Stroop interference paradigm (Stroop, 1935). Words are displayed on the screen and participants are required to name the colour that the word is printed in. In the original task, the semantic congruence of the word-colour paring is manipulated (i.e. red, is congruent and red, is incongruent) and differences in response times to congruent vs incongruent trials is understood as semantic interference. In the emotional variation, rather than manipulation of the semantic congruence, word valence is instead manipulated. Participant response time to name the colour of a word is recorded for neutral (e.g. chair) vs threatening (e.g. fight) words. The difference in response times between these conditions (the Stroop effect) indicates a failure to attend exclusively on the target dimension of colour. Longer response times for words (or sometimes images) of threatening valence indicates an attentional bias towards threat.

The emotional Stroop task was one of the earliest and most widely used paradigms to demonstrate attentional bias in anxious adults (for reviews, see Bar-Haim et al., 2007; Mogg & Bradley, 1998; Williams et al., 1996). Research has shown that individuals with higher anxiety levels do exhibit a threat-related attentional bias in this task (McLeod, 1991). However, the robustness of these findings has been questioned. Some researchers suggest that anxious participants may process both neutral and threatening stimuli similarly, and that the repeated exposure to threatening words may simply heighten state anxiety, particularly in individuals with high trait anxiety (HTA). This increase in anxiety could slow overall response times to threat words, rather than indicating a specific attentional bias. These concerns led to the development of the dot-probe paradigm, which avoids the potential confound of heightened anxiety caused by repeated response towards threatening stimuli, offering a more precise measure of attentional bias.

The Dot Probe Paradigm (McLeod et al., 1986).

In the dot probe paradigm two stimuli are displayed on a screen, one neutral and one threatening. The stimuli then disappear, and a small probe appears in the location of one of the images. Participants are required to respond as quickly as possible to the location of the probe, usually by clicking a key indicating the probe is in either the left or right hemisphere of the screen. Response latencies are understood to be indicative of prior attentional allocation of participants, whereby longer response times indicate attention to stimuli opposite to the location of the probe. Attentional bias towards threat is inferred by participant responding faster to probes that replace threat related rather than neutral stimuli. This task addresses some limitations of the emotional Stroop, as in the dot probe task participants are required to respond to a neutral stimulus (the probe). Therefore, there is no concern that latencies may occur from general arousal or response bias. A wealth of research has demonstrated attentional bias towards threat in anxious individuals using this paradigm (Bar-Haim et al., 2007; Mogg & Bradley, 1998).

Schmukle (2005) raised concerns about the reliability of the dot-probe task in non-clinical samples. Across two studies employing word and picture stimuli, Schmukle evaluated both internal consistency and one-week test-retest reliability, concluding that the dot-probe paradigm is unreliable for assessing attentional allocation.

Emotional Spatial Cuing Task (Stormark et al., 1995).

The emotional spatial cueing task was developed to distinguish between facilitation of attention toward threatening stimuli and delayed disengagement from them—two aspects of attentional bias that cannot be separated in the emotional Stroop task. The task is a variant of Posner's spatial cuing paradigm (Posner, 1980), where a cue appears in one of two locations and is followed by a target. The target is presented either in the same location of the cue (congruent condition) or in the alternate location (incongruent condition). Performance in detecting or identifying the target is typically quicker in the valid condition compared to the invalid condition. Relative attentional engagement among participants is linked to faster response times in the valid cue condition, while delayed disengagement is associated with slower responses in the invalid cue condition. In the emotional variant of this task, the valence of the cue is manipulated (Stormark et al., 1995). A threat related attentional bias is found when validity effects (performance on incongruent minus performance on congruent trials) is larger for threat related than neutral cues. Additionally, the emotional spatial cueing task enables a distinction between attentional facilitation and delayed disengagement. Attentional facilitation to threat is indicated by faster responses to threat-related cues in congruent trials. In contrast, delayed disengagement from threat is observed through slower responses to incongruent targets following threatening cues, compared to neutral cues.

However, it is important to acknowledge the limited generalizability of these findings, as participants in this task are explicitly instructed to attend to the cue images. As a result, the proposed heightened attentional capture by threat in individuals with anxiety cannot be accurately assessed as ecologically individuals are not specifically attending towards threatening cues, instead they appear peripherally (Cisler & Koster, 2010).

Emotional Anti-Saccade Task (Chen et al., 2015).

Based on the anti-saccade task (Hallet, 1978), which is commonly used to measure inhibitory attentional control, the task involves the presentation of peripheral stimuli. Participants are instructed to either perform a prosaccade (look toward the stimulus) or an anti-saccade (look away from the stimulus) in response to task instructions. The prosaccade response is largely reflexive and therefore, to successfully anti-saccade participants are required to inhibit the prepotent prosaccade response, prior to the generation of a volitional saccade. Correct anti-saccade performance necessitates the recruitment of attentional control abilities, which has been validified by studies finding increased activation in attentional control related brain regions such as the prefrontal cortex during this task (Ettinger et al., 2008). In the emotional variant of this task, stimuli valence is manipulated allowing for the measurement of attentional bias, whereby increased latency in anti-saccade performance is found in high trait anxious individuals when stimuli are of threatening valence (Ansari & Derakshan, 2009).

Summary of Paradigms:

In summary, these four paradigms, though distinct, have consistently demonstrated an attentional bias toward threat in anxious individuals across various conditions. A meta-analysis by Bar-Haim et al. (2007) of 150 studies on attentional bias in anxiety confirmed the robustness of this effect across different anxiety disorders and experimental methods. However, Bar-Haim et al. highlight a notable gap in research examining this relationship in children, particularly in longitudinal studies. A key limitation of the paradigms mentioned above is their suitability for use with child samples. For instance, tasks like the anti-saccade task have been found to present reliability issues in children, as reported by Klein and Fischer (2005).

Furthermore, although the relationship between attentional bias and anxiety is consistently observed, there is considerable variability in this effect. Studies report substantial differences in effect sizes and even in the direction of attentional bias, with some findings suggesting a bias toward threat and others indicating avoidance (Dudeney et al., 2015). This variability has led researchers to highlight the potential moderating role of attentional control—the capacity to flexibly shift and direct attention—in shaping the relationship between attentional bias and anxiety (Derryberry & Reed, 2002; Eysenck et al., 2007).

Moderating Mechanism of Attentional Control

Recent research has highlighted the role of attentional control in shaping attentional biases, as discussed by Derryberry and Reed (2002) and Eysenck et al. (2007). Cisler and Koster (2010) describe attention as a multistage process. Initially, attention may be automatically drawn toward threatening stimuli (facilitated attention) through bottom-up processes, driven by stimulus salience and evolutionary predispositions. However, once attention is captured by a threat, individuals can use top-down attentional processes to either disengage quickly or to maintain attention towards the threat (delayed disengagement). Consequently, the extent of attentional bias toward threat in anxiety may be moderated by these top-down processes. Researchers have therefore theorized that attentional biases in anxiety may stem from deficits in top-down attentional control, rather than solely from heightened stimulus salience or bottom-up mechanisms. This impaired top-down control may explain the persistence of attentional biases toward threats, as it limits an individual's ability to shift attention away from threatening stimuli.

Attentional control is generally understood to comprise three key subcomponents: inhibition, shifting, and updating (Eysenck et al., 2007; Miyake et al., 2000). *Inhibition* refers to the ability to ignore task-irrelevant stimuli that might distract from current goals. *Shifting* involves staying focused on task-relevant stimuli while switching between tasks or adjusting to changes in task requirements. *Updating* entails monitoring new information and replacing outdated or irrelevant information. Evidence for anxiety's impact on attentional control comes from various sources. Tasks such as the Stroop, go/no-go, and visual search tasks have consistently shown reduced performance in inhibition among individuals with high trait and state anxiety (see Bar-Haim et al., 2007; Shi et al., 2019, for a review). Meanwhile, tasks like the Wisconsin Card Sorting Task (Caselli et al., 2004) and the Comprehensive Trail Making Test (Orem et al., 2008) have revealed anxiety-related impairments in attentional shifting ability. Tasks like the N-back have demonstrated deficits in both performance and efficiency for the updating component of attentional control in individuals with higher anxiety levels (Wong et al., 2013).

Eysenck's Attentional Control Theory posits that anxiety-related attentional biases arise from deficits in attentional control, which hinder individuals' ability to shift attend away from negative stimuli, potentially leading to distressing, repetitive thoughts. The moderation model proposed by Field and Lester (2010) extends this idea, suggesting that the influence of attentional control on anxiety and attentional bias varies with developmental factors. Specifically, as attentional control matures, individuals become better equipped to inhibit attention to threats. In those with delayed or deficient development of attentional control, however, attentional biases are more likely to persist, potentially increasing the risk of anxiety.

Derryberry and Reed (2002) found that trait-anxious individuals only displayed an attentional bias toward threat when they self-reported low attentional control abilities, whereas those with high attentional control showed no attentional bias, regardless of anxiety level. This finding was reinforced by Peers and Lawrence (2009), who observed that individuals with poor attentional control exhibited delayed disengagement from emotional faces in a rapid serial visual presentation task, whereas those with good attentional control did not experience this difficulty. However, both studies relied on self-reported attentional control rather than behavioural measures. This reliance on self-report methods, such as the Attentional Control Scale (ACS), remains a limitation in research on attentional control and bias toward threat (see Todd et al., 2022).

The literature supports a link between deficient attentional control and anxiety; however, the proposed moderating role of attentional control in the development of attentional bias and anxiety lacks substantial empirical backing. Gaining a clearer understanding of the developmental trajectory of these constructs is crucial for elucidating the roles that attentional control and attentional bias may play in the onset and progression of anxiety.

Developmental Course

The moderation model proposed by Field and Lester (2010) provides predictions about the development of attentional bias and attentional control. According to this model, as children grow, some develop attentional control abilities that moderate the relationship between anxiety and attentional bias. Specifically, while all young children (4-7yrs) initially exhibit a bias toward threat, differences in this bias based on anxiety levels are expected to emerge later as attentional control abilities mature. Similarly, Kindt and Van den Hout (2001) propose that all young children show attentional bias toward threat regardless of anxiety, whereas differences in bias related to anxiety become apparent only in older children.

Evidence of this shift in attentional bias towards threat across development is highlighted in a range of different studies. Eye tracking data of preschoolers completing a free viewing task found that all young children (both anxious and non-anxious) displayed an attentional bias towards threat (Dodd et al., 2014). Further, Kindt et al. (1997a) found no difference in attentional bias towards spider specific stimuli for spider phobic vs non phobic children. Whilst Perez-Olivaz et al. (2008) found that anxious children over the age of 10 showed an attentional bias towards threat, whereas children younger than 10 did not show a bias relative to control children. A recent meta-analysis by Dudeney et al. (2015), which reviewed 38 studies with 4,221 participants, examined the developmental trajectory of attentional bias toward threat in anxiety. They found that anxious children display an attentional bias toward threat relative to non-anxious children, though to a lesser degree than anxious adults. This bias was also modulated by age, with the difference in attentional bias between anxious and control children increasing with age. These findings align with Kindt and Van den Hout's (2001) proposition that attentional biases in anxiety diverge as children develop.

The moderation model also predicts a developmental trajectory for attentional control, suggesting that while all young children may display deficient attentional control abilities, differences between high- and low-anxious individuals emerge over time. A meta-analysis by Shi, Sharpe, and Abbott (2019) partially supports this model, finding that age moderated the relationship between anxiety and attentional control deficits. Specifically, the impact of anxiety on attentional control was more pronounced in adults than in children in behavioural studies, though no studies directly compared these age groups. Furthermore, while some studies have used behavioural methods to concurrently measure attentional control and attentional bias in adults (e.g., Mazidi et al., 2021), no research has yet behaviourally examined these constructs in children. Existing studies on their interaction rely on self-report measures of attentional control, such as the Attentional Control Scale (ACS; Susa et al., 2012; Campbell & Kertz, 2019). Recent work by Todd et al. (2022) has raised concerns about the validity of self-reported attentional control measures; in a large non-clinical sample (n = 209), they found no correlation between the ACS and performance on the anti-saccade task, suggesting that the ACS might reflect perceived, rather than actual, attentional control ability. This finding is consistent with Quigley et al. (2017), who suggested that attentional control deficits in highly trait-anxious individuals may reflect metacognitive distortions rather than objective deficits. These findings underscore the need for behavioural measures of attentional control in research.

In summary, while empirical studies suggest that attentional control is involved in anxiety and some theoretical models suggest it may moderate attentional bias across development, the field faces certain limitations. There is an overreliance on self-report measures of attentional control, and developmental theories lack support from research directly comparing different age groups.

Requirement for New Methodology and Current Study

Two key gaps remain in the literature: (a) a lack of studies that examine attentional control and attentional bias independently using behavioural measures, and (b) studies that compare developmental trajectories between children and adults. Although some behavioural paradigms, such as the anti-saccade task, can measure both attentional control and attentional bias, research has indicated that this task may be unreliable for children and children (Klein & Fischer, 2005). Consequently, new methodologies are needed to address these limitations effectively.

Research in related fields has highlighted promising new tasks for studying attentional control. Visual short-term memory (VSTM) is commonly defined as the ability to hold visual or spatial information in mind for a short period. VSTM tasks assess this ability by measuring differences in the number of items individuals can maintain in memory, often using a behavioural capacity index termed *K* (e.g., Cowan, 2001). A typical VSTM task involves presenting a memory array, followed by a blank screen, and then a test array. Participants are required to retain the memory array in working memory while evaluating the test array. Adults show significant variability in VSTM capacity (Awh & Vogel, 2006), with recent findings suggesting that poor top-down attentional control may contribute to these differences. For example, adults with low VSTM capacity tend to perform worse on tasks that require them to resist attentional capture by irrelevant items (Fukuda & Vogel, 2009) and benefit more from stimulus properties that reduce the need for attentional control compared to high-capacity individuals (Linke et al., 2011). Additionally, Astle et al. (2014) found that performance on their VSTM task was linked to an individual's ability to filter out distractions, rather than merely reflecting visual memory capacity. Astle et al. presented participants with memory arrays containing either two targets, four targets, or two targets alongside two distractors. Using electrophysiological scalp recordings, they demonstrated that performance reductions in the VSTM task reflected poor selectivity rather than limitations in working memory capacity. Moreover, comparisons between children and adults revealed that typically developing children can also effectively filter out distractors in this task.

The VSTM task used by Astle et al. (2014) is particularly valuable for two main reasons. First, it is sensitive to developmental changes, proving effective for both adult and child samples. Second, performance in this task is likely associated with prefrontal attentional control. In this task, a memory array containing both target and distractor items is presented, and participants must remember the location and orientation of the target items when they reappear in the test array. By incorporating distractors, the task can assess attentional control, with variations in the number of distractors and monitoring of distractor-related conflict allowing for a nuanced measurement of this construct.

To advance our understanding of the roles of attentional control and bias in the development of anxiety, it is crucial to employ methodologies that assess these constructs across developmental stages. Accordingly, we propose that the VSTM task could be adapted to assess both attentional bias and attentional control. Attentional control can be measured by comparing task performance in the presence and absence of distractors, whereas attentional bias can be assessed by examining changes in task performance relative to the threat level of the distractor stimuli. In this way, incorporating distractors with varying levels of threat into Astle et al.'s (2014) VSTM task would address key gaps in the literature by offering (1) a behavioural measure of attentional control and (2) reliable applicability across both adult and child samples.

Chapter 3

Research Questions / Hypotheses

Relationship Between Attentional Control, Attentional Bias, and Anxiety

This study aims to investigate the interplay between attentional control, attentional bias, and anxiety, focusing on how these constructs influence performance in tasks involving distractors. Please refer to the introductory section for a brief overview of task design. The following research questions and hypotheses guide this investigation:

Adult Sample

1. **Measurement of Attentional Control:**
   - **Impact of Distractors on Performance:**
     - **Research Question 1a:** Does the presence of distractors significantly affect performance?
     - **Hypothesis 1a:** Participants will exhibit decreased performance when distractors are present compared to trials without distractors due to the increased mental strain resulting from the required recruitment of attentional control.
   - **Performance Comparison Between Conflict and Non-Conflict Trials:**
     - **Research Question 1b:** Is performance on non-conflict trials higher than on conflict trials?
     - **Hypothesis 1b:** Participants will demonstrate superior performance in non-conflict trials compared to conflict trials, reflecting the role of attentional control in managing competing information.
2. **Interaction Between Attentional Control and Anxiety:**
   - **Deficient Attentional Control in Individuals with Higher Anxiety:**

- **Research Question 2:** Do individuals with higher anxiety exhibit deficits in attentional control?
- **Hypothesis (Distractor Presence) 2a:** An interaction is expected between the presence of distractors and anxiety levels, whereby participants with higher anxiety will show a more pronounced decline in performance, compared to participants with lower anxiety, when distractors are present. Specifically, as anxiety increases, the performance gap between trials with and without distractors will widen.
- **Hypothesis (Conflict) 2b:** Similarly, an interaction is expected between response conflict and anxiety levels, whereby participants with higher anxiety will show more pronounces decline in performance for conflict compared to non-conflict trials.

3. **Overall Attentional Bias:**
   - **Perceived Threat and Performance:**
     - **Research Question 3:** Is there a general tendency for individuals to find it harder to ignore distractors perceived as threatening?
     - **Hypothesis 3:** A significant decrease in performance is anticipated as the perceived threat of distractors increases. Conversely, if no such bias exists, we would expect no performance differences related to perceived threat.
4. **Attentional Bias Toward Threat in Anxious Individuals:**
   - **Comparative Attentional Bias:**
     - **Research Question 4:** Do participants with higher anxiety show a greater attentional bias toward threat than those with lower anxiety? Is there an interaction between perceived threat and anxiety on performance?

- **Hypothesis 4:** Individuals with higher anxiety are expected to demonstrate a stronger attentional bias toward threatening stimuli, resulting in decreased performance compared to non-anxious participants. An interaction effect is anticipated, where increased perceived threat will further exacerbate the performance deficits in anxious individuals.

Child Sample

We aim to investigate the same research questions within the child sample, though the hypotheses differ due to the anticipated developmental influences on these constructs, as outlined in the moderation model (Field & Lester, 2010). While the main effects of attentional control and attentional bias toward threat are expected to remain consistent across development, predictions diverge for the interaction between these constructs and anxiety in children. The hypotheses for the child sample are as follows:

- **Research Question 1a:** Does the presence of distractors significantly affect performance?
    - **Hypothesis 1a (Child Sample):** As with the adult sample, children will exhibit decreased performance when distractors are present compared to trials without distractors.
- **Research Question 1b:** Is performance on non-conflict trials higher than on conflict trials?
    - **Hypothesis 1b (Child Sample):** Children will demonstrate better performance in non-conflict trials compared to conflict trials.
- **Research Question 2:** Do individuals with higher anxiety exhibit deficits in attentional control?
    - **Hypothesis 2a (Distractor Presence, Child Sample):** An interaction between distractor presence and anxiety levels is expected, such that children with higher

anxiety will show a more pronounced decline in performance when distractors are present. Specifically, as anxiety increases, the performance gap between trials with and without distractors will widen. Although this effect size is expected to be smaller than in adults, as attentional control ability differences are still developing within this age group.

- **Hypothesis 2b (Response Conflict, Child Sample):** Similarly, an interaction between response conflict and anxiety levels is expected, with higher-anxiety participants showing a more pronounced performance decline for conflict trials compared to non-conflict trials.

- **Research Question 3:** Is there a general tendency for individuals to find it harder to ignore distractors perceived as threatening?
  - **Hypothesis 3 (Child Sample):** A significant decrease in performance is anticipated as the perceived threat of distractors increases, with all children expected to show an attentional bias toward threat.
- **Research Question 4:** Do participants with higher anxiety show a greater attentional bias toward threat than those with lower anxiety? Is there an interaction between perceived threat and anxiety on performance?
  - **Hypothesis 4 (Child Sample):** Unlike the adult sample, children with higher anxiety are not expected to exhibit a stronger attentional bias toward threatening stimuli than children with lower anxiety. All children are anticipated to show a similar bias, regardless of anxiety levels, as the moderation model suggests that the development of attentional control in non-anxious individuals leads to this divergence in threat response.

Chapter 4

General Methodological Approach of the VSTM Task

This section provides a general overview of the methodological approach used in the task. For more detailed information on the task design, readers are encouraged to consult the methods sections of the pilot studies in Chapter 5 and the final study design outlined in Chapter 6.

Our Visual Short-Term Memory (VSTM) task, adapted from Astle et al. (2014), is a change-detection task that incorporates task-irrelevant distractors. The presence of these distractors allows us to measure attentional control, specifically the ability to ignore distractors and attend to target items. This task setup enables manipulation of executive demands in three keyways:

1. **Attentional Control** – by comparing performance (accuracy or response time) in conditions with and without distractors.
2. **Conflict Monitoring** – by comparing performance when targets and distractors suggest conflicting responses.
3. **Memory Load** – by varying the number of target items that need to be remembered.

A critical feature of this task is the manipulation of threat valence in distractor images, which allows us to concurrently measure attentional bias and attentional control. By systematically varying the threat levels of distractors, we can examine how perceived threat influences these cognitive processes. For example, high-threat distractors may capture attention and reduce task performance more significantly than low-threat or neutral distractors, especially in individuals with higher anxiety. This distinction enables us to assess whether deficits in attentional control are more pronounced when processing threatening stimuli versus neutral stimuli, thus indicating an attentional bias toward threat.

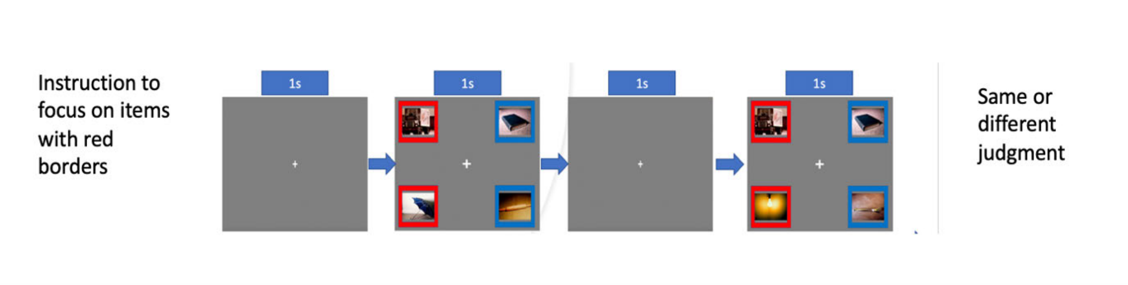
The task consists of a basic sequence: a first display, or "memory array," presents several target and distractor objects. This is followed by a blank screen (the "retention interval"), and then a test array where participants judge if any target objects have changed from the initial display. An example of a trial from early piloting is shown in Figure 1.

When distractors are included, only a subset of items in the memory array (the target items) are designated as important, requiring participants to determine whether these specific items have changed in the test array. Individuals with poor attentional control, often struggle to ignore distractor items, which can undermine task performance. This is especially true in conflict trials, where distractors change while targets do not, or vice versa. Individuals who attend to the distractors face conflicting information about whether the target have changed, creating ambiguity in their required response. In contrast, individuals with high attentional control typically filter out distractors effectively, showing a smaller performance deficit on conflict versus non-conflict trials (Astle et al., 2012). Performance is also generally higher on trials without distractors, as attentional control resources are not needed to filter out irrelevant items. The difference in performance between trials with or without distractors is an effective measure of how well participants can filter out the distractors, through the recruitment of attentional control.

The distractor images used in this study were selected from the International Affective Picture System (IAPS; Bradley & Lang, 2007) and consist of 20 images, equally divided into neutral (10) and threatening (10) categories. By examining performance with both neutral and threatening distractors, we aim to determine whether attentional control deficits are general (as indicated by performance with neutral distractors) or specific to threatening stimuli (as indicated by performance with threatening distractors), which may be associated with anxiety.

Figure 1:

Exemplar Trial



Note: This figure illustrates an exemplar trial of the task. The trial begins with the presentation of four images: two targets (bordered in red) and two distractors (bordered in blue). Each image is displayed for 1 second, followed by a 1-second retention interval during which the images are not shown. After this interval, the images are redisplayed for an additional second, during which the participant must judge whether the images have changed. The clear distinction between targets and distractors is emphasized by the color-coded borders.

Due to the novel methodology, a unique piloting process was required to fine-tune and develop the parameters of the method. An effective method requires an appropriate level of difficulty for the participants. If the task is too difficult, we are likely to see a "floor" effect, whereby all participants score at a very low level, likely not above chance, which would prevent the usefulness of the task as differences between groups are not apparent. Similarly, if the task is too easy, we are likely to see a "ceiling" effect, whereby all participants score at a very high level, again hindering our ability to find statistically significant differences between groups. Thus, fine-tuning the difficulty of the task is an important first step.

Difficulty can be manipulated in multiple ways, with simpler adjustments including variations in display times, retention intervals, or the number of stimuli displayed on the screen. More complex changes could involve modifying the nature of the changes required for detection, such as rotating an image rather than changing it entirely.

Further piloting allows for the examination of expected effect sizes, which will inform the required sample size for the study. Piloting also enables decisions regarding which statistical methods will be used.

For the child sample, we will utilize the Revised Children's Manifest Anxiety Scale (RCMAS; Reynolds & Richmond, 1985), while the State-Trait Anxiety Inventory (Spielberger et al., 1983) will be administered to adults. Both measures are recognized for their validity and reliability within their respective target populations. Analysing the distribution of anxiety scores from these scales will guide our future statistical analyses. Should the distribution indicate a clear separation between high and low anxiety groups, we will consider employing multivariate analysis. Conversely, if the distribution appears more normal, a linear model may be more appropriate.

In summary, due to the need for a novel method for concurrently measuring attentional control and attentional bias, an iterative approach of piloting and adjusting parameters is most appropriate. Small pilot studies of adult participants recruited from the University of Sydney's psychology undergraduate SONA program will be used. This approach allows for fine-tuning and adjustment of key experimental parameters to ensure accurate measurement. Adjusting the difficulty of the task is crucial in preventing ceiling and floor effects, while analyses on effect sizes and distributions of anxiety scores will guide decisions surrounding statistical methods to be employed.

Chapter 5

Piloting

Overview

The primary objective of the piloting process was to optimize the parameters of our adapted Visual Short-Term Memory (VSTM) task to best measure attentional control and attentional bias. Achieving this required finding a task difficulty level that reveals performance differences across conditions. Further, various methods of measuring attentional control and attentional bias, such as comparing conflict vs. non-conflict trials and distractor vs. no-distractor conditions, were explored.

Pilot Study 1 established baseline performance using standard display parameters from the original VSTM task (Astle et al., 2014). In Pilot Studies 2a and 2b, task difficulty was modified by shortening target display times, assessing whether increasing difficulty in this manner would prevent ceiling effects and allow for condition-specific performance differences. Pilot Study 3 increased difficulty further through an increased memory load and added a no-distractor condition to further refine the measurement of attentional control. Finally, Pilot Study 4 examined how participants' subjective threat ratings of distractors aligned with the pre-coded threat classifications, providing insights into individual variations in threat perception and its potential influence on our measurement of attentional bias.

Table 1 summarizes the results from pilot studies 1, 2a, 2b, and 3, highlighting key design features, results, and conclusions. This table underscores the primary adjustments made to achieve an optimal task difficulty level (around 75%) that is sensitive enough to detect performance differences across conditions and between individuals. Detailed information on each pilot study, including methods, results with figures, and discussion, is provided in the sections below. Pilot Study 4 is discussed in greater depth, as it forms the basis for decisions regarding the final methodology and experimental design.

Common Apparatus and Stimuli:

All pilot studies were conducted in-person in a group setting of up to 4 participants per session. All participants completed the task on a Windows 7 PC using PsychoPy2 to control stimulus presentation. Stimuli were displayed on a 24-inch Dell monitor (1920 × 1080 resolution, 60 Hz refresh rate). With all stimuli 13.02cm width and 9.77cm height.

Common Task Design:

Each pilot study commenced with the presentation of task instructions, followed by 12 practice trials to familiarize participants with the task procedure. During these practice trials, the memory array display time was set at 2000 ms to ensure participants could fully understand the task demands.

The main task consisted of 64 neutral trials and 64 threat trials. For Pilot Studies 3 and 4, an additional 64 trials without any distractor were included, increasing the total number of trials. All trials were organized into blocks of 32, with a brief break provided after every 16 trials to mitigate potential fatigue.

To maintain experimental rigor, the order of trial presentation was counterbalanced across participants in all studies, ensuring that order effects did not confound the results.

Table 1:

Summary of Pilot Studies

Pilot Study	**Subject Numbers**	**Design**	**Display Time**	**Results**	**Conclusions**
1	35	2 Target, 2 Distractor	300ms	Performance on the task was consistently high, with the mean proportion of correct trials at 86.71%. No significant differences were observed in performance for trials with neutral versus threatening distractor stimuli, nor between	The high accuracy observed in Pilot Study 1 suggested that participants were able to process and retain the stimuli with relative ease, indicating a ceiling effect that may have obscured potential differences between conditions. To address this, increasing task difficulty

				conflict trials and non-conflict trials. Additionally, there was minimal differences in response times across trial types.	by reducing the display times during the retention interval could require participants to more quickly filter out irrelevant distractor stimuli.
2a	12	2 Target, 2 Distractor	200ms	Mean proportion of correct responses at 85.55%, and the distribution of scores showed a negative skew. no notable differences were observed between neutral and threatening conditions or conflict and non-conflict response conflicts for either performance or response time metrics	Task performance remained high, with no notable differences between conditions, even for conflict and non-conflict trials, and a negatively skewed distribution of overall accuracy. This pattern suggests that despite the increased difficulty with a reduced display time of 200ms, the task may still be too easy, resulting in a ceiling effect that limits our ability to detect subtle differences between conditions.
2b	6	2 Target, 2 Distractor	100ms	We observed very high-performance scores, with mean accuracy at 88% and a negatively skewed distribution. no notable differences in performance emerged between conditions, nor were there distinctions in response times.	The continued high performance suggests that display time manipulation alone may not be sufficient to uncover differences across conditions. Other avenues for increasing the difficulty of the task will be explored.
3	12	3 Target, 3 Distractor: inclusion of No distractor condition.	400ms	Mean accuracy of 77%, with differences across conditions, 67.1%, 83.2% and 85.1% for neutral, threat and no distractor conditions respectively. However, response times remained consistent across conditions.	Performance was significantly lower with the three distractor 3 target paradigm, further differences across conditions indicated that the optimal difficulty for the task was achieved. Interestingly participants performed worse in the neutral condition compared to the threat condition, this counterintuitive result is

	explored further in Pilot Study 4

Note: The above table describes key methodological features of the first four pilot studies with short summaries of results and discussion of implications.

Pilot Study 1

Methods:

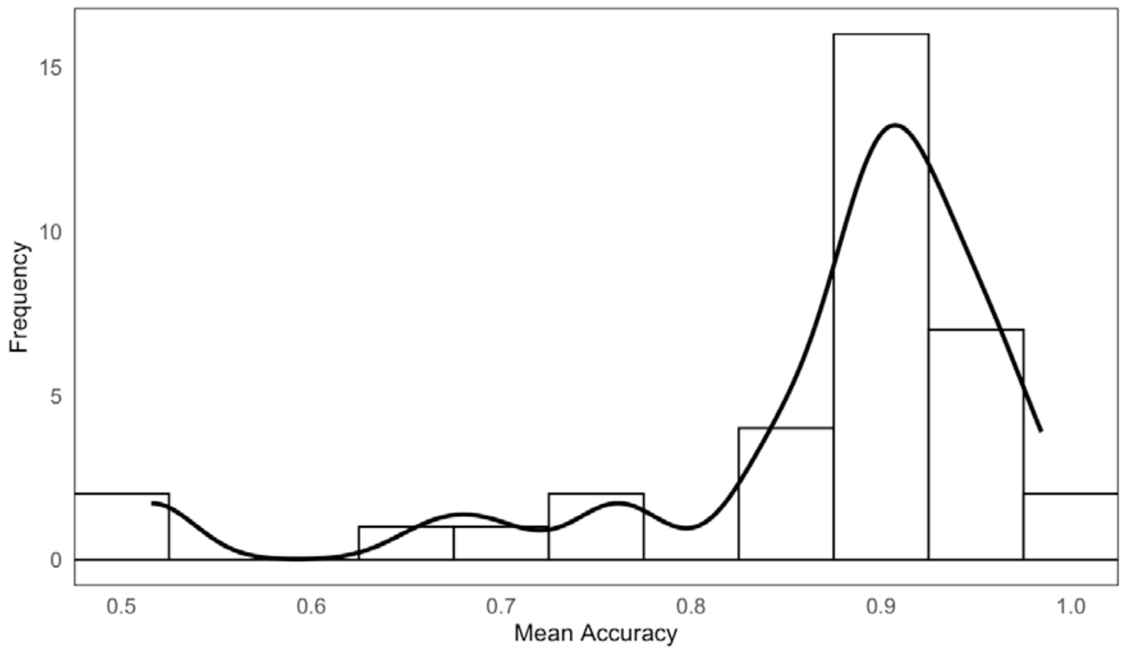
The first variation of the study involved the presentation of two targets and two distractor objects. The four items would appear on the screen for 300ms followed by a 1000ms retention interval (as adapted from Astle et al., 2014). Followed by the representation of the stimuli (targets and distractors) with a prompt for a same or different judgment of the target images. 35 Participants, 23 identified as female, were recruited from the university's undergraduate psychology SONA pool with mean age of 20.65. Participants completed the WM task as well as the RCMAS measure of anxiety. The presentation of which was counterbalanced between participants.

Results and Discussion:

Performance on the task was consistently high, with the mean proportion of correct trials at 86.71%. The distribution of overall performance scores is shown in Figure 2, revealing a negatively skewed pattern, with a large proportion of participants scoring at or above 90%. No significant differences were observed in performance for trials with neutral versus threatening distractor stimuli (Figure 3), nor between non-conflict trials (where both targets and distractors changed or both stayed the same) and conflict trials (where targets changed while distractors did not, or vice versa), as illustrated in Figure 4. Additionally, response time data in Figure 5 further suggests that the 300ms display time may have been too long, as minimal differences in response times across trial types were evident.

The high accuracy observed in Pilot Study 1 suggests that participants were able to process and retain the stimuli with relative ease, indicating a ceiling effect that may have obscured potential differences between conditions. To address this, increasing task difficulty by reducing the display times during the retention interval could require participants to more quickly filter out irrelevant distractor stimuli. Such adjustments would likely place greater demands on attentional control and may reveal condition-specific performance differences. In Pilot Studies 2a and 2b, we investigate the same experimental design while progressively shortening the display times of the stimuli to explore the impact of increased task difficulty on attentional filtering and retention.

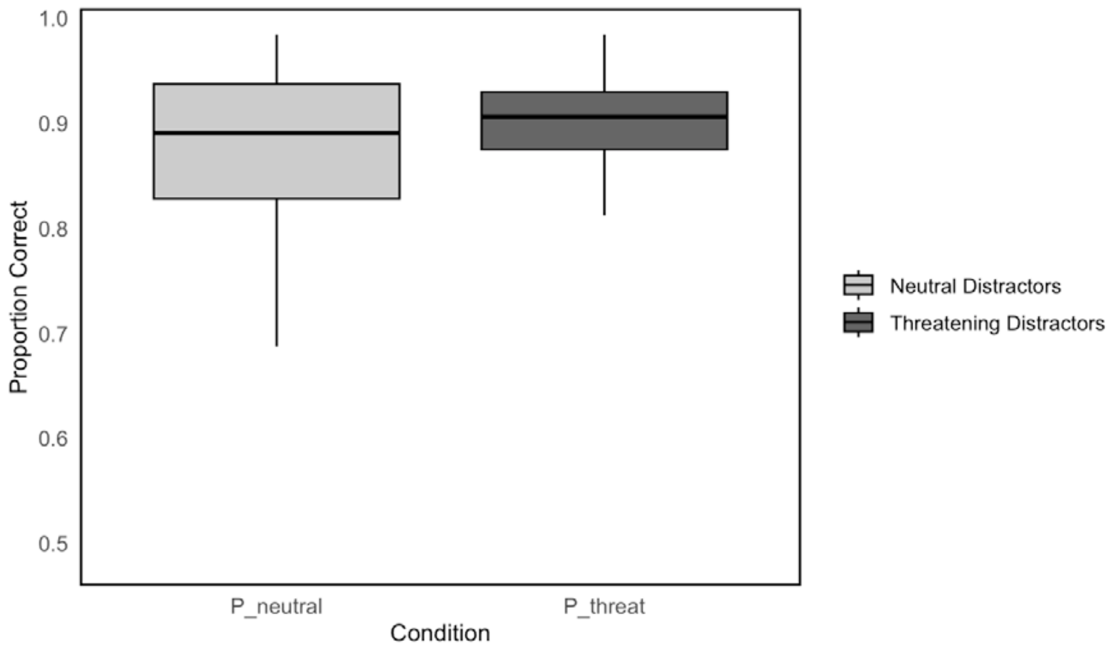
Figure 2:
Distribution of Total Accuracy: Pilot 1



Note: Frequency histogram displaying total accuracy of individual participants for Pilot Study 1 (n = 35). The mean proportion correct was 0.867, with the density curve highlighting a negatively skewed distribution.

Figure 3:

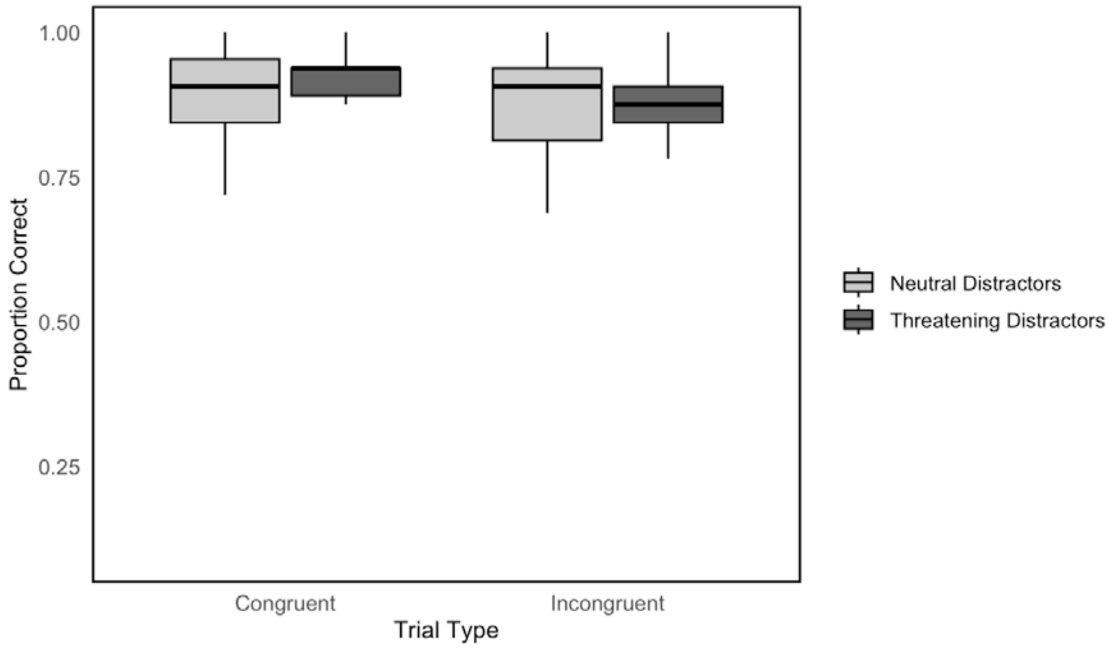
Proportion of Correct Responses Across Stimulus Conditions: Pilot 1



Note: Boxplots displaying performance across stimulus conditions for Pilot 1. The median proportion of correct responses, represented by the black lines, is .891 for neutral distractors and .906 for threatening distractors. Outliers are omitted.

Figure 4:

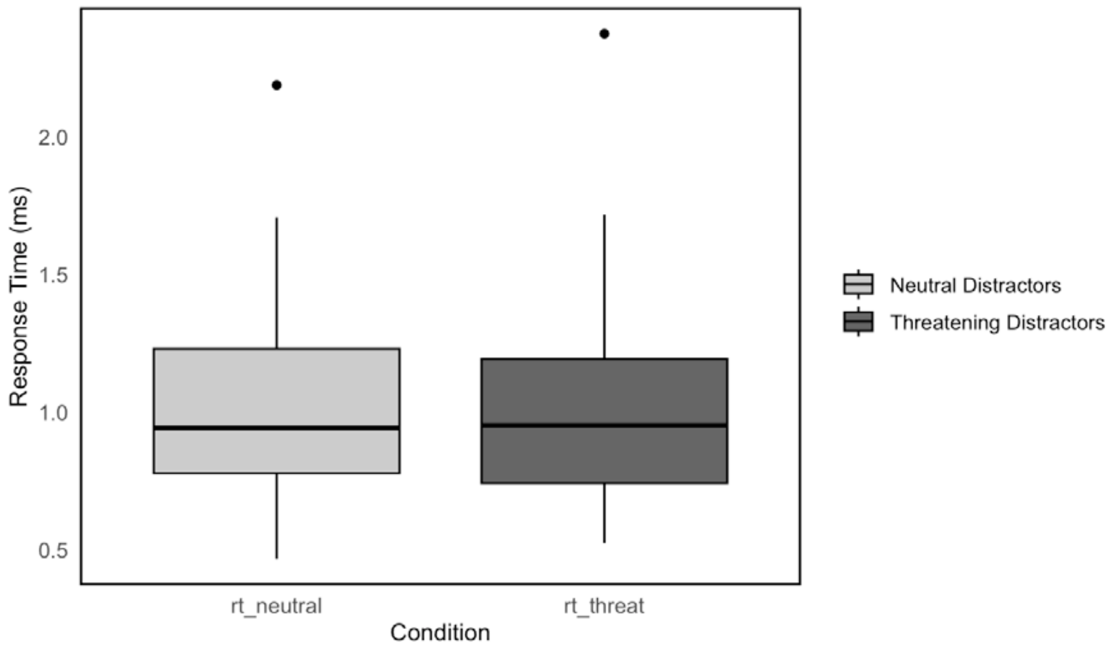
Proportion of Correct Responses Across Trial Type and Stimulus Condition: Pilot 1



Note: Boxplots displaying the distribution of correct responses across trial type and stimulus condition for Pilot 1. The black horizontal line represents the median proportion of correct responses. Outliers are omitted for clarity.

Figure 5:

Response times Across Neutral and Threatening Distractors: Pilot 1



Note: Boxplots displaying the distribution of response times across neutral and threatening distractors for pilot 1. The median response times are 942ms for neutral distractors and 952ms for threatening distractors. Outliers are included.

Pilot Study 2a

Methods:

In Pilot Study 2a, we recruited 12 participants (6 identifying as female, mean age = 20.08) from the university's undergraduate psychology SONA pool. For this variation of the task, the display times for the stimuli were reduced to 200ms. Shortening the display time was intended to increase task difficulty, requiring participants to filter out irrelevant distractor stimuli more rapidly and attend to target stimuli within a limited timeframe. This adjustment aimed to test whether a more challenging task could help mitigate the ceiling effect observed in Pilot Study 1, potentially revealing performance differences across conditions that may not have been evident with longer display times.

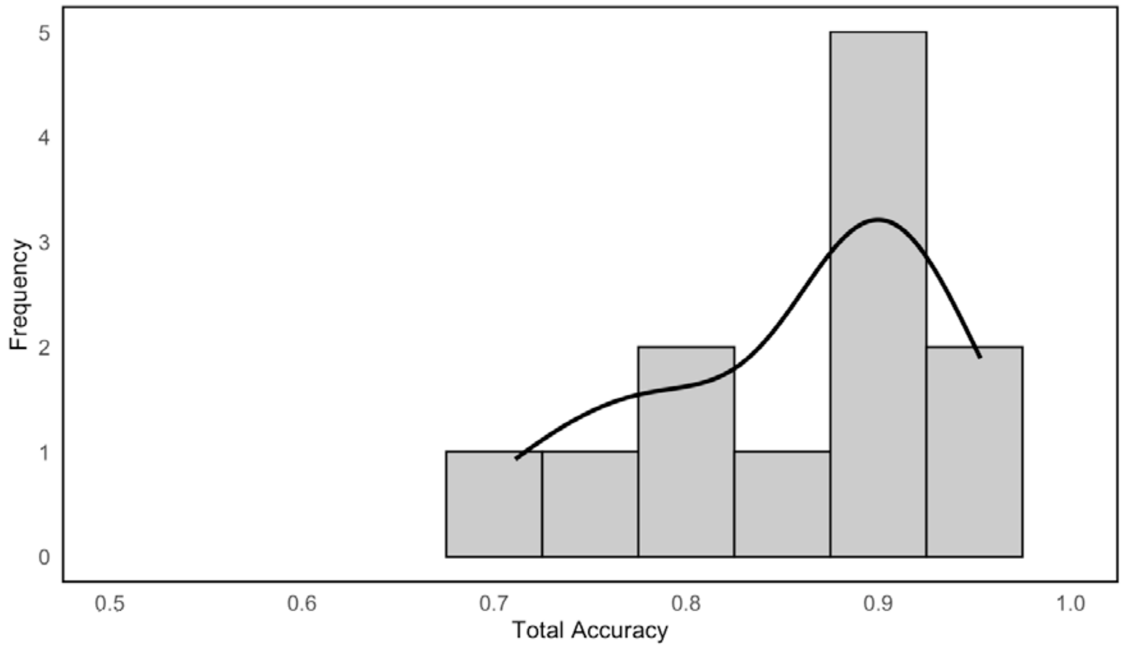
Results and Discussion:

Once again, task performance was high, with the mean proportion of correct responses at 85.55%, and the distribution of scores showed a negative skew (see Figure 6). Additionally, no notable differences were observed between neutral and threatening conditions for either performance or response time metrics (Figure 7 and Figure 8, respectively). Conflict also appeared to have minimal impact on performance across conditions, as shown in Figure 9.

This pattern suggests that despite the increased difficulty with a reduced display time of 200ms, the task may still be too easy, resulting in a ceiling effect that limits our ability to detect subtle differences between conditions. To address this, Pilot Study 2b will further shorten the display time to 100ms to explore whether this additional increase in difficulty better reveals performance variability across conditions.

Figure 6:

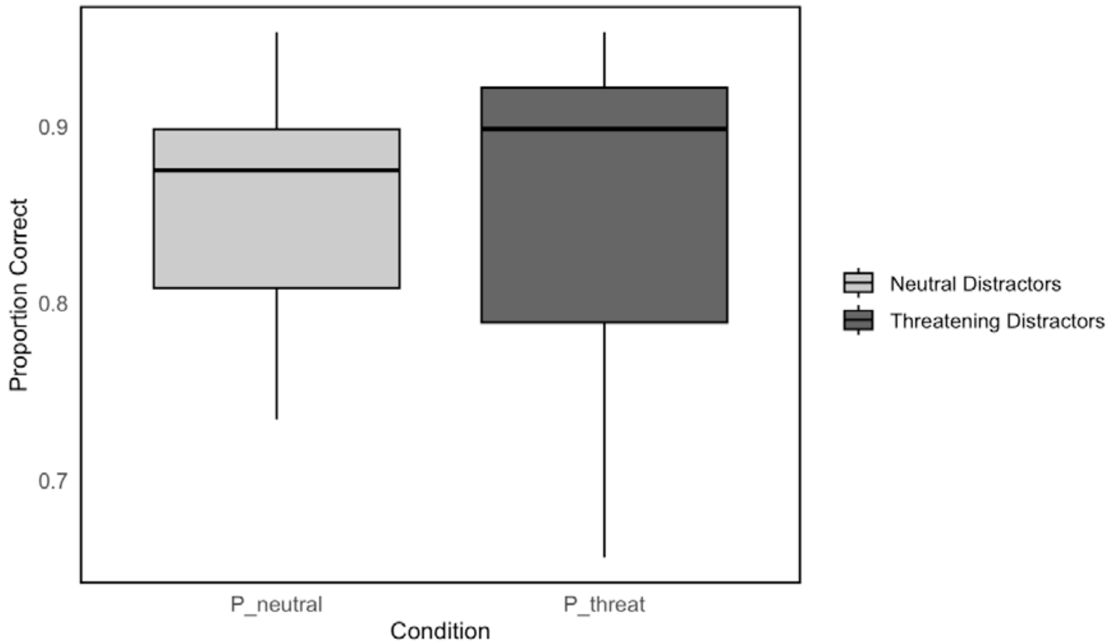
Distribution of Total Accuracy: Pilot 2a



Note: Frequency histogram displaying total accuracy of individual participants for Pilot Study 2a (n = 12). The density curve highlights a negatively skewed distribution.

Figure 7:

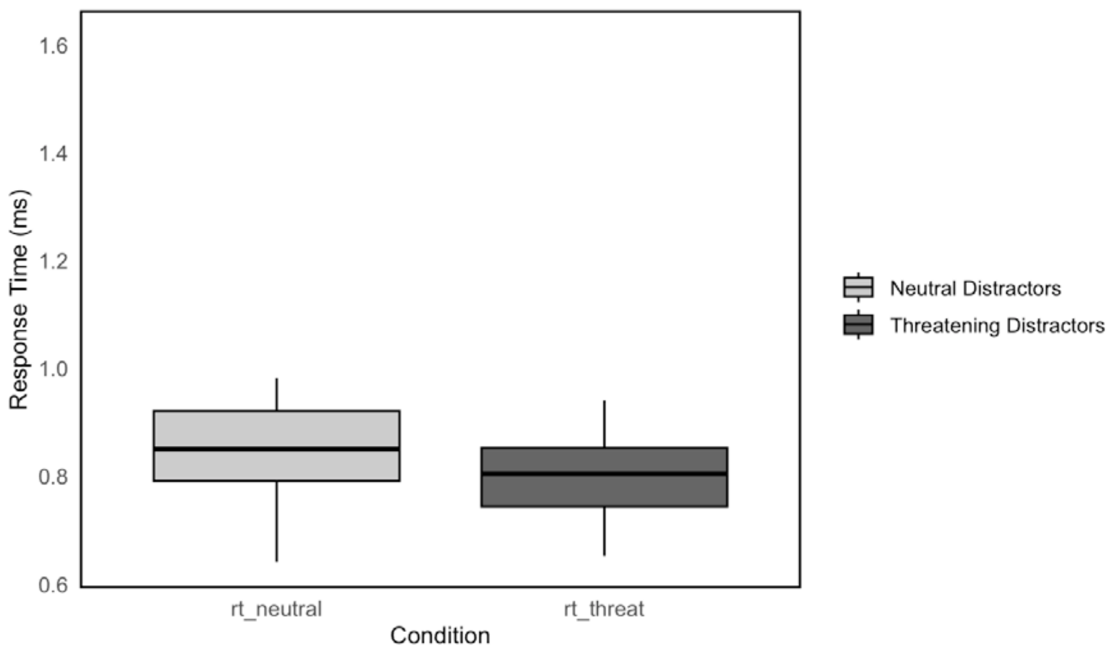
Proportion of Correct Responses Across Stimulus Conditions: Pilot 2a



Note: Boxplots displaying performance across stimulus conditions for pilot study 2a. The median proportion of correct responses, represented by the black horizontal lines, is .875 for neutral distractors and .898 for threatening distractors. Outliers are omitted.

Figure 8:

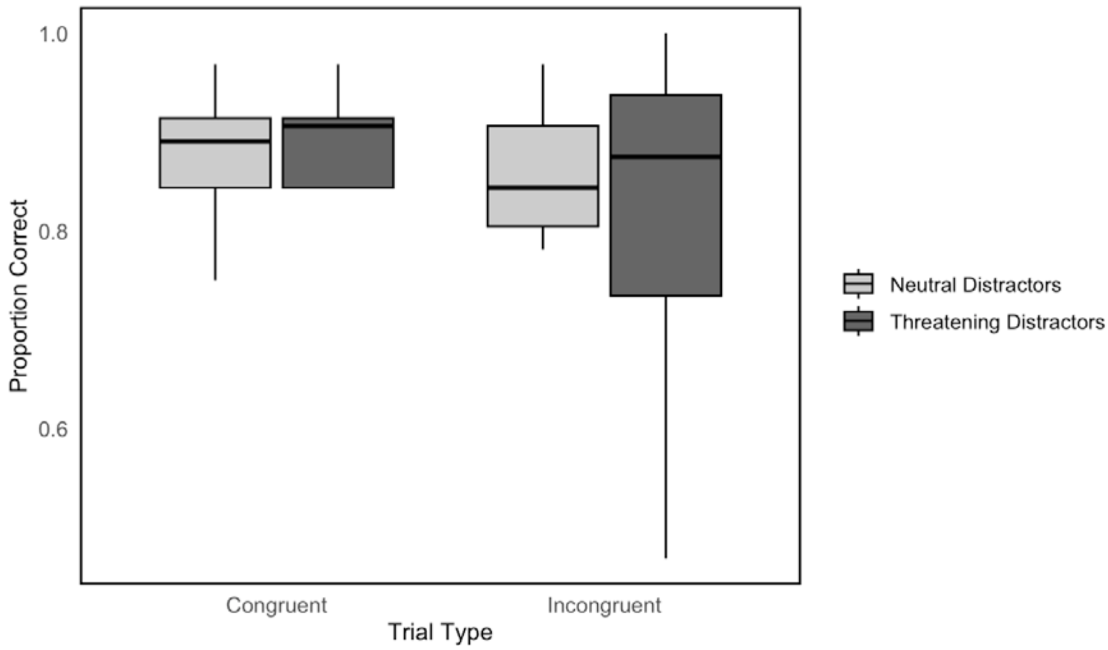
Response times Across Neutral and Threatening Distractors: Pilot 2a



Note: Boxplots displaying the distribution of response times across neutral and threatening distractors for pilot study 2a. The median response times are 850ms for neutral distractors and 804ms for threatening distractors. Outliers are included.

Figure 9:

Proportion of Correct Responses Across Trial Type and Stimulus Condition: Pilot 2a



Note: Boxplots displaying the distribution of correct responses across trial type and stimulus condition for pilot study 2a. The black horizontal line represents the median proportion of correct responses. Outliers are omitted for clarity.

Pilot Study 2b

Methods:

In Pilot Study 2b, we recruited 6 participants (3 identifying as female, mean age = 20.33) from the university's undergraduate psychology SONA pool. For this iteration, the display times for the stimuli were further reduced to 100ms. This shorter display time was expected to make the task even more challenging, requiring participants to rapidly filter out irrelevant distractor stimuli and attend to the target stimuli under more demanding conditions. By increasing task difficulty, we aimed to further address the ceiling effect observed in Pilot

Study 1 and 2a, with the hope of uncovering performance differences across conditions that might not emerge with longer or moderate display times.

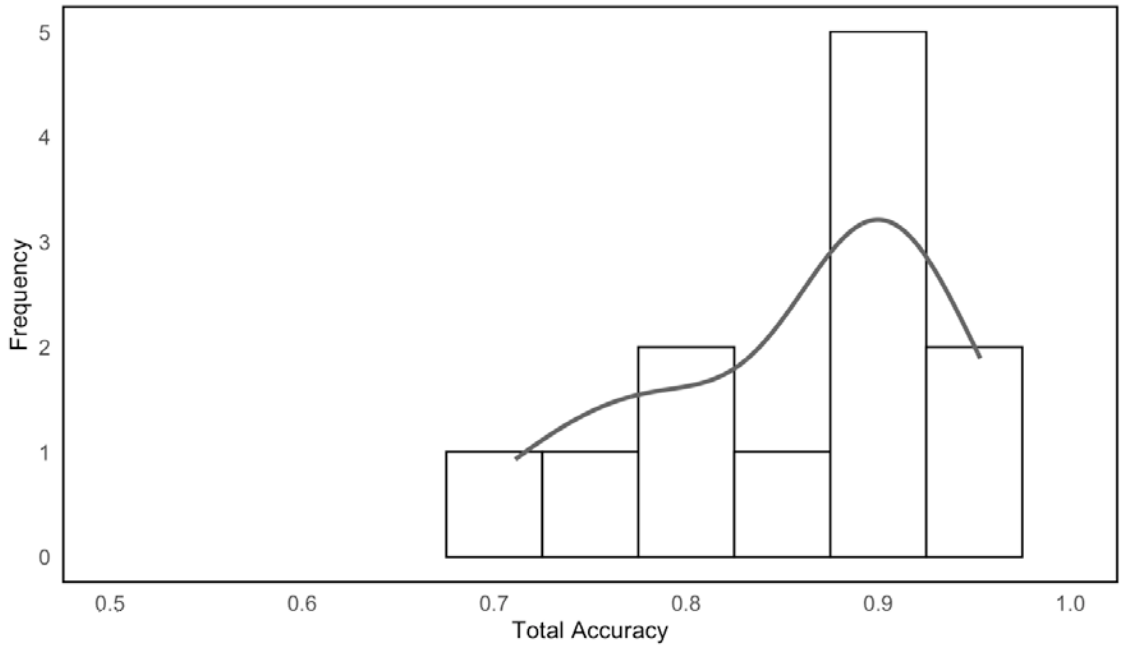
Results and Discussion:

Once again, we observed very high-performance scores, with mean accuracy at 88% and a negatively skewed distribution (Figure 10). Additionally, no notable differences in performance emerged between conditions (Figure 11and Figure 12), nor were there distinctions in response times (Figure 13).

Despite the very brief display time of 100ms, participants continued to perform at a high level, suggesting that this manipulation alone may not be sufficient to uncover differences across conditions. These persistently elevated accuracy scores highlight the need for additional adjustments to the task design. To address this, Pilot Study 3 will increase the memory load by expanding from 2 targets and 2 distractors to 3 targets and 3 distractors, thereby enhancing task difficulty and potentially mitigating ceiling effects.

Figure 10:

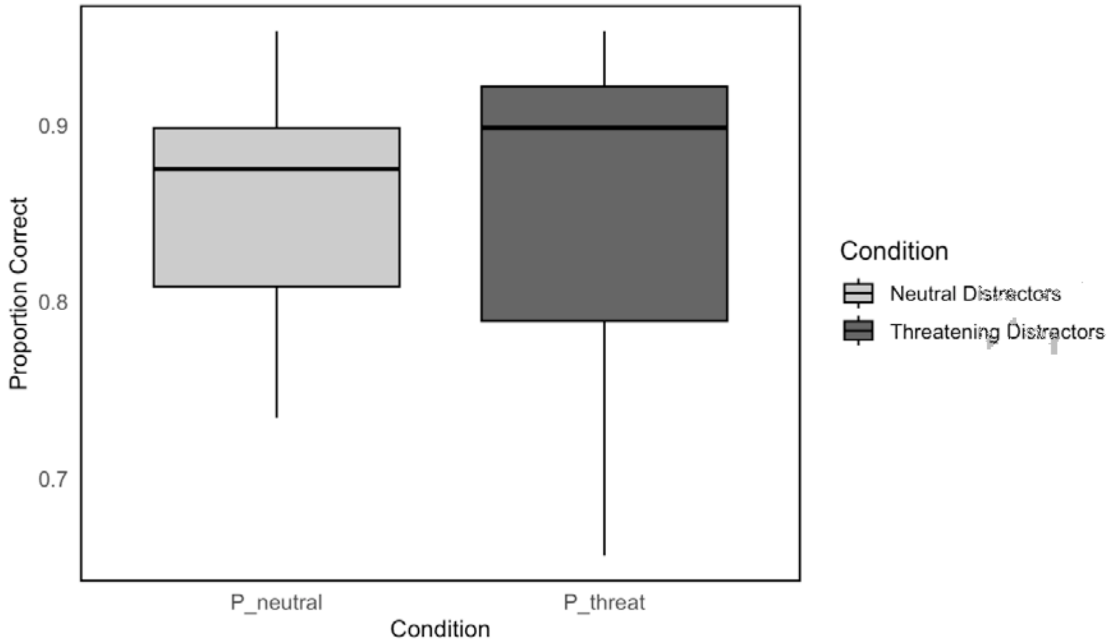
Distribution of Total Accuracy: Pilot 2b



Note: Frequency histogram displaying individual participants total accuracy as a proportion of correct answers for pilot study 2b (n = 6). The density curve highlights a negatively skewed distribution.

Figure 11:

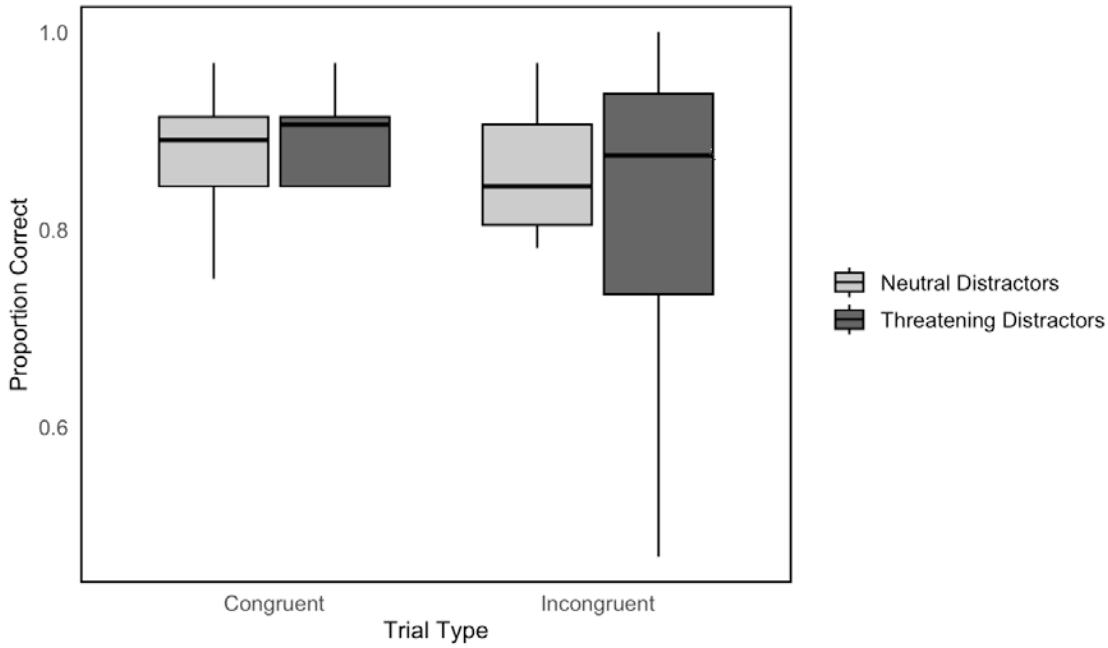
Proportion of Correct Responses Across Stimulus Conditions: Pilot 2b



Note: Boxplots displaying performance across stimulus conditions for study 2b. The median proportion of correct responses, represented by the horizontal black lines, is .891 for neutral distractors and .914 for threatening distractors. Outliers are omitted.

Figure 12:

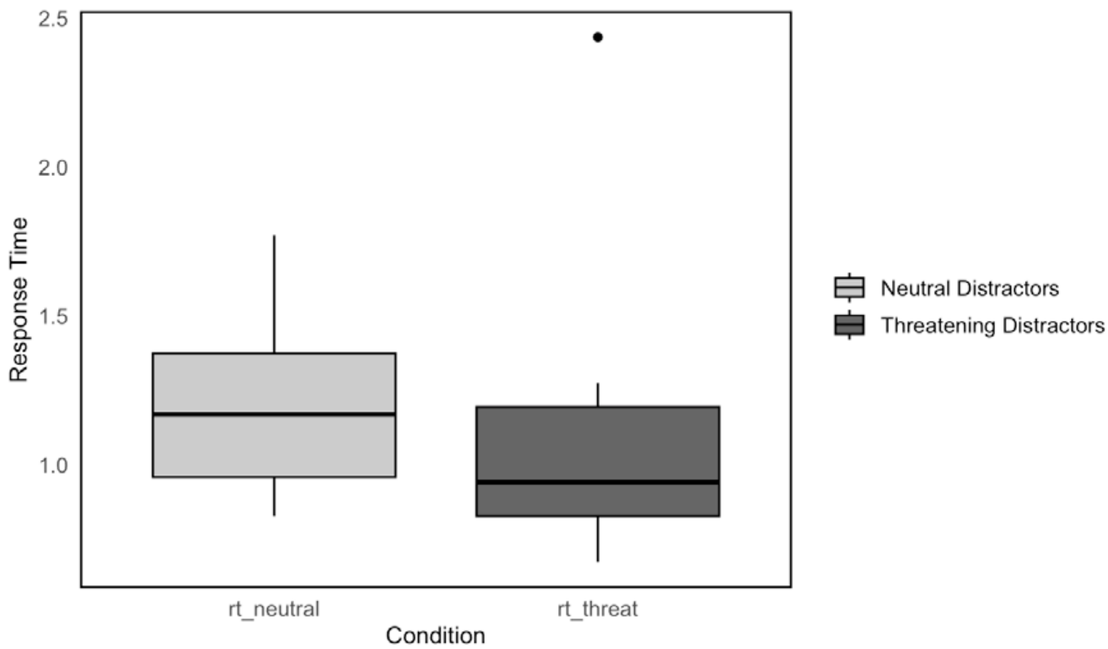
Proportion of Correct Responses Across Trial Type and Stimulus Condition: Pilot 2b



Note: Boxplots displaying the distribution of correct responses across trial type and stimulus condition for pilot study 2b. The horizontal black line represents the median proportion of correct responses. Outliers are omitted for clarity.

Figure 13:

Response times Across Neutral and Threatening Distractors: Pilot 2b



Note: Boxplots displaying the distribution of response times across neutral and threatening distractors. The median response times are 1168ms for neutral distractors and 940ms for threatening distractors. Outliers are included.

Pilot Study 3

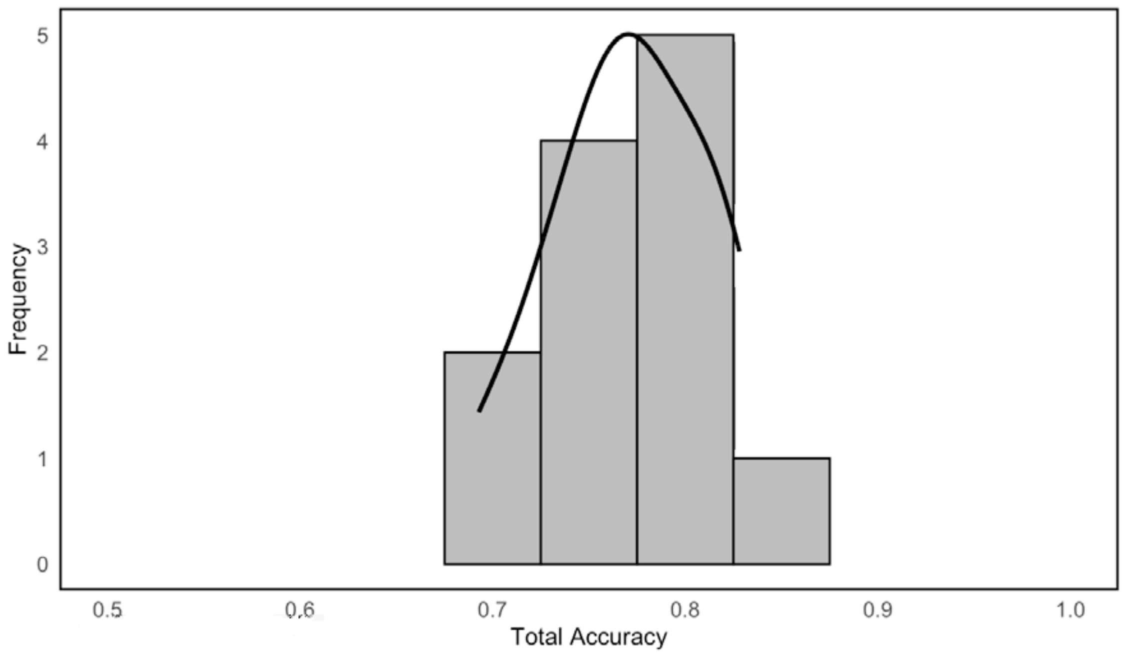
Methods:

Following the consistently high performance observed with 2-target and 2-distractor trials across various presentation lengths, we introduced a more challenging task variation with 3 targets and 3 distractors. This adjustment was intended to increase task difficulty by placing greater strain on working memory as well as introducing more to be ignored items. Additionally, we introduced a trial block without distractors, as previous trials showed minimal differences between conflict and non-conflict conditions. This block provided a means of comparing working memory capacity and attentional control in a way that extends beyond the conflict of distractor and target conditions, offering an alternative approach to examining attentional control mechanisms. For this variation, display times were set at 400ms.

Results:

A sample of 12 participants was recruited from the university's psychology SONA pool (female = 6, mean age = 21.5). Performance on this variation of the task was notably lower than in previous studies, with an average accuracy of 77% (see Figure 14). Differences in performance were observed across conditions, with mean accuracy rates of 67.1% for neutral distractors, 83.2% for threatening distractors, and 85.1% for no-distractor conditions (Figure 15). However, response times remained relatively consistent across all conditions (Figure 16).

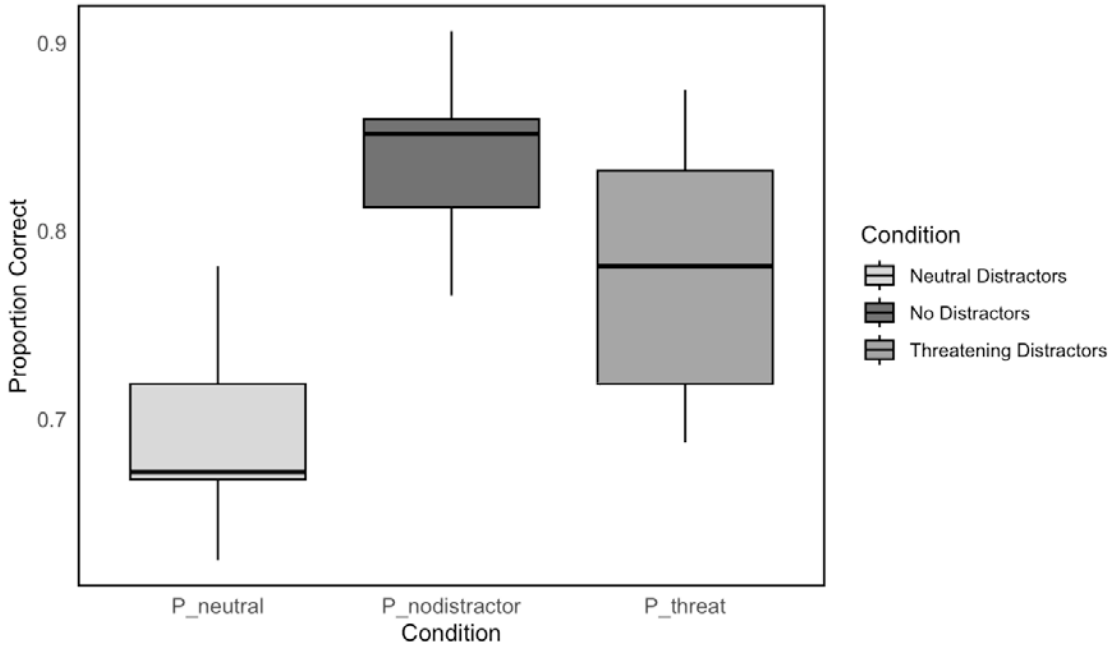
Figure 14:
Distribution of Total Accuracy: Pilot 3



Note: Frequency histogram displaying total accuracy of individual participants for Pilot Study 3 (n = 12). The density curve approximates a normal distribution.

Figure 15:

Proportion of Correct Responses Across Stimulus Conditions: Pilot 3

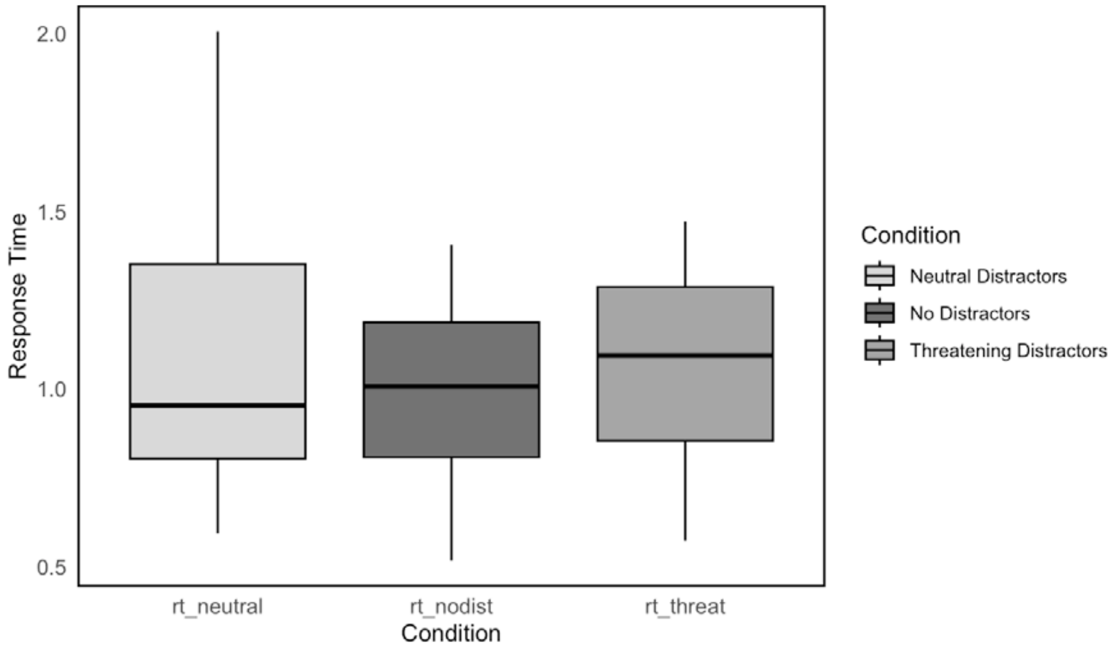


Note: Boxplots displaying performance across stimulus conditions in pilot study 3.

Horizontal black lines represent median scores, outliers are omitted for clarity.

Figure 16:

Response times Across Neutral and Threatening Distractors: Pilot 3



Note: Boxplots displaying the distribution of response times across neutral and threatening distractors. The median response times are 953ms for neutral distractors, 1094ms for threatening distractors and 1007ms for no-distractor condition. Outliers are omitted for clarity.

Discussion:

Performance in Pilot Study 3 was notably lower, suggesting that the increased memory load introduced by using 3 targets and 3 distractors effectively raised task difficulty. The inclusion of a no-distractor condition further emphasized the importance of attentional control, as performance dropped in trials with distractors. This finding suggests that the presence of distractors likely captured participants' attention, necessitating greater attentional control to filter out irrelevant stimuli and maintain task performance. Interestingly, participants performed better on trials with threatening distractors compared to neutral ones. We hypothesize that this may be due to a hypervigilance response to threatening stimuli, potentially resulting in heightened mental effort during these trials. However, as response times did not vary significantly, there is limited evidence to support this increased cognitive engagement. To investigate this unexpected result further, Pilot Study 4 includes a manipulation check assessing participants' subjective threat perceptions in comparison to the predefined threat levels of the distractor images.

Pilot Study 4

Method:

In Pilot Study 4, we included a manipulation check to further investigate the IAPS threatening images, aiming to understand the unexpected pattern of results observed in Pilot Study 3, where participants performed worse on trials with neutral stimuli compared to those with threatening stimuli. After completing the main task, participants were presented with all distractor images consecutively and were asked to rate each image on its perceived threat level. The question provided to participants was: "Next you will be asked to rate a range of images on how threatening you perceive them to be." Each image was accompanied by a 5-point scale, ranging from 1 ("Not threatening") to 5 ("Highly threatening"). See Figure 17 for exemplar screengrabs. Further, we present data on the distribution of anxiety scores for our sample on the STAI.

Figure 17:

Participants' Perceived Threat Ratings for Distractor Images

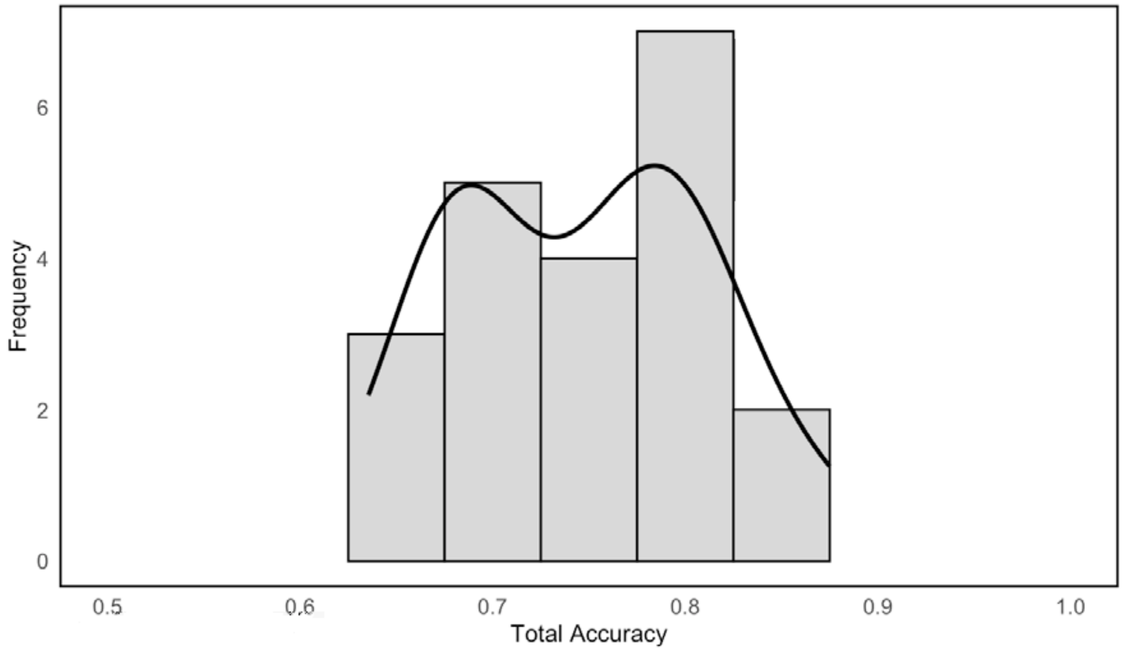
Note: This figure displays exemplar screengrabs of the rating scale used by participants to evaluate the perceived threat of distractor images. Participants rated each image on a scale from 1 (Not Threatening) to 5 (Highly Threatening). This rating process followed the task, allowing for a comprehensive assessment of individual perceptions of threat associated with the images.

Results:

We recruited 21 participants from the university's psychology SONA pool (13 females; Mean age = 21.48). Consistent with Pilot Study 3, task performance was well-distributed, with a mean accuracy of 74.6% (see Figure 18). Performance differed across threat, neutral, and no-distractor conditions (Figure 19), while accuracy differences between conflict and non-conflict trials were minimal (Figure 20). Response times also showed minimal variation across conditions (Figure 21). Interestingly, participants rated neutral and threatening distractor stimuli similarly in terms of perceived threat (Figure 22). Exploratory analyses suggested an order effect, with lower performance on the first block of trials compared to later blocks, possibly introducing noise due to counterbalancing procedure (Figure 23). Scores on the STAI approximated a normal distribution, supporting the treatment of anxiety as a continuous linear variable (Figure 24).

Figure 18:

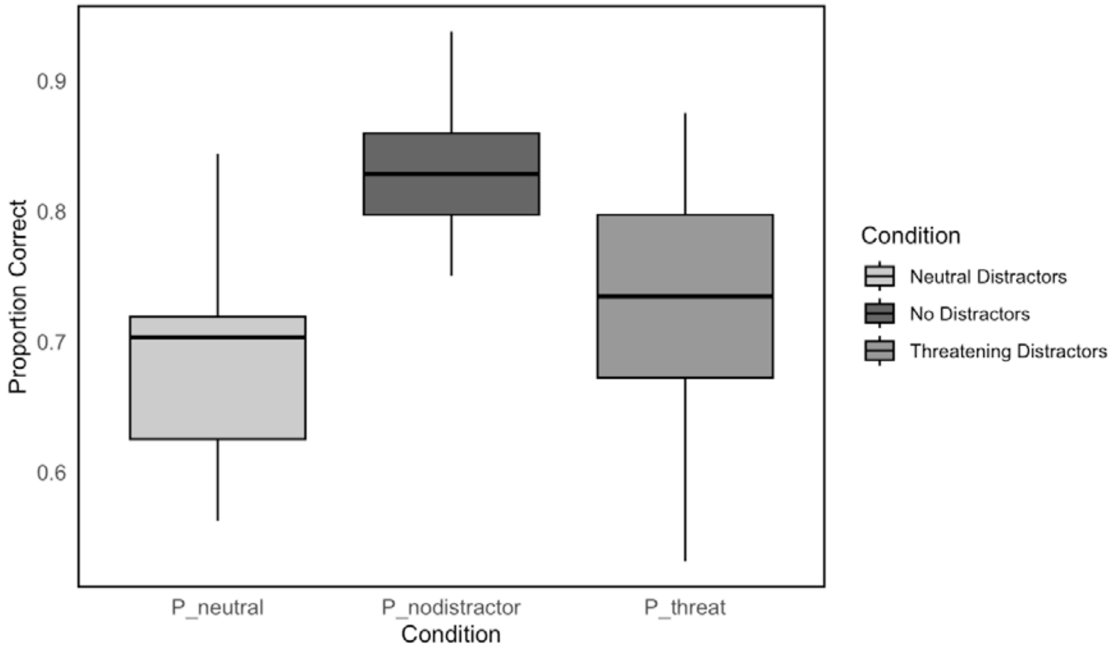
Distribution of Total Accuracy: Pilot 4



Note: Frequency histogram displaying total accuracy of individual participants for Pilot Study 4 (n = 21). The density curve approximates a normal distribution.

Figure 19:

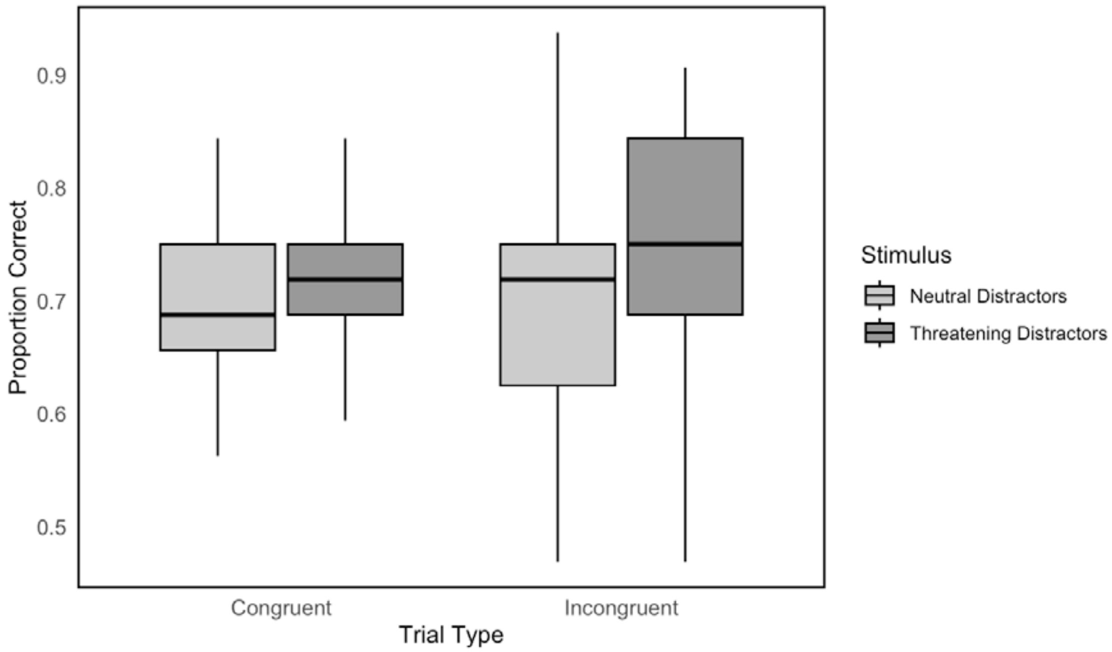
Proportion of Correct Responses Across Stimulus Conditions: Pilot 4



Note: Boxplots displaying performance across stimulus conditions in pilot study 4. The median proportion of correct responses is .703 for neutral distractors .734 for threatening distractors, and .797 for the no-distractor condition. Outliers are omitted.

Figure 20:

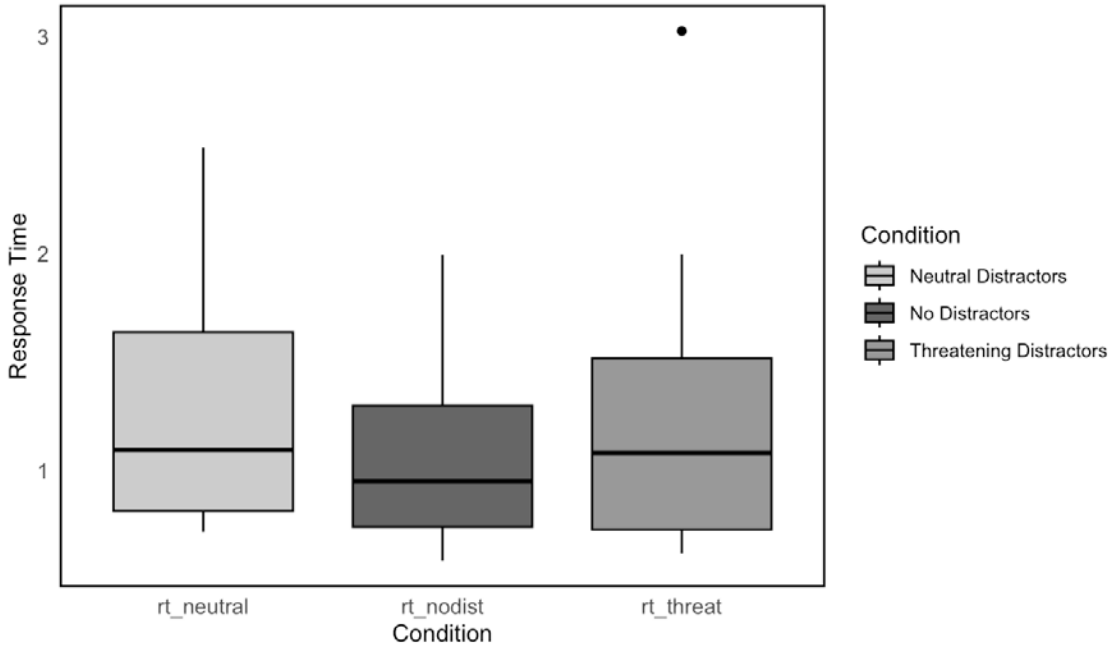
Proportion of Correct Responses Across Response Conflict Condition: Pilot 4



Note: Boxplots displaying performance across response conflict conditions in pilot study 4. "Congruent" (i.e. non-conflict) conditions represented trials where the targets and distractors exhibited the same outcomes. While "incongruent" (i.e. conflict) were trials where target and distractor outcomes competed. Outliers are omitted.

Figure 21:

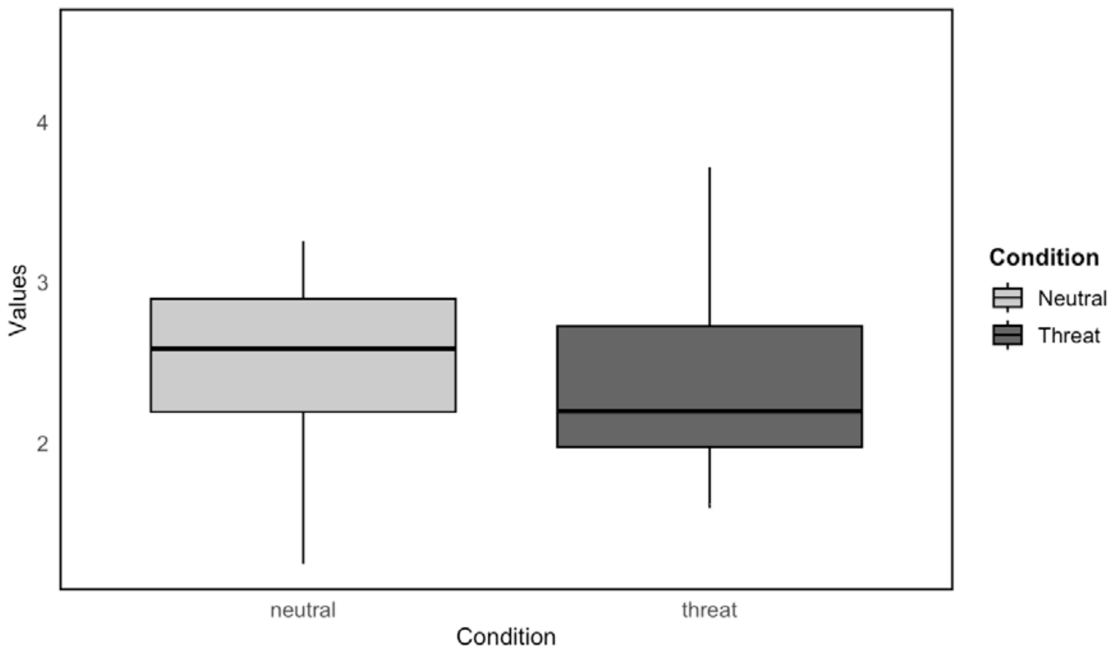
Response times Across Distractor Conditions: Pilot 4



Note: Boxplots displaying the distribution of response times across neutral and threatening distractors. The median response times are 1094ms for neutral distractors, 1080ms for threatening distractors and 950ms for no-distractor condition. Outliers are omitted for clarity.

Figure 22:

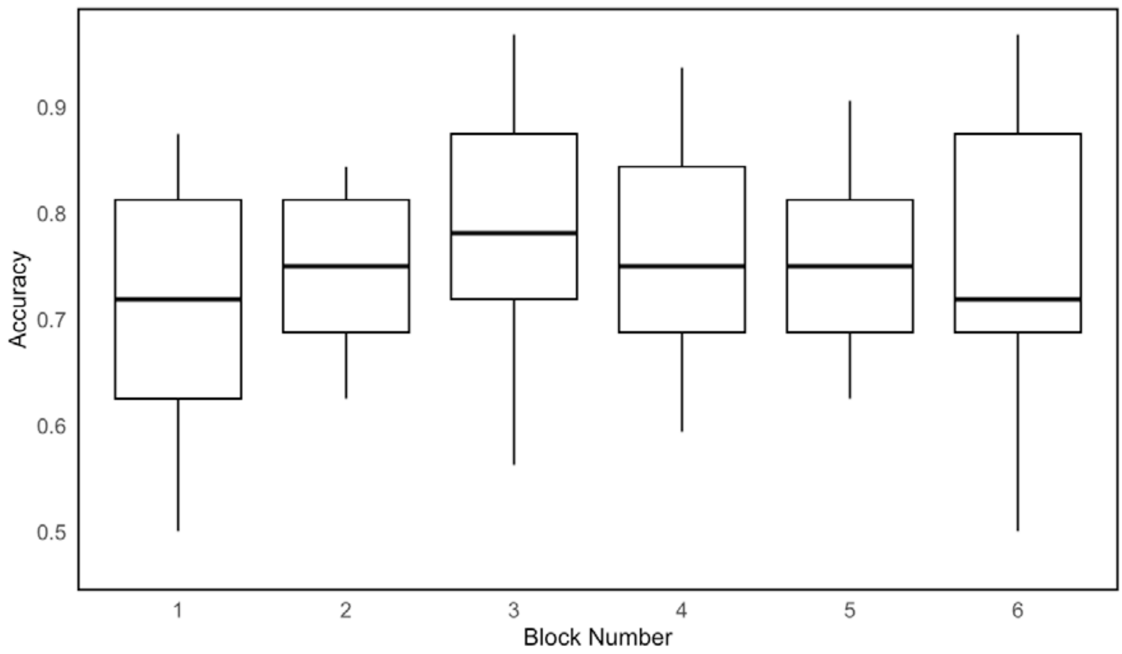
Perceived Threat Ratings of Neutral and Threatening Distractor Stimuli: Pilot 4



Note: Boxplots displaying perceived threat ratings for groups of images previously encoded as neutral and threatening, used as distractor stimuli. The median threat rating for each condition is represented by the black line within the box.

Figure 23:

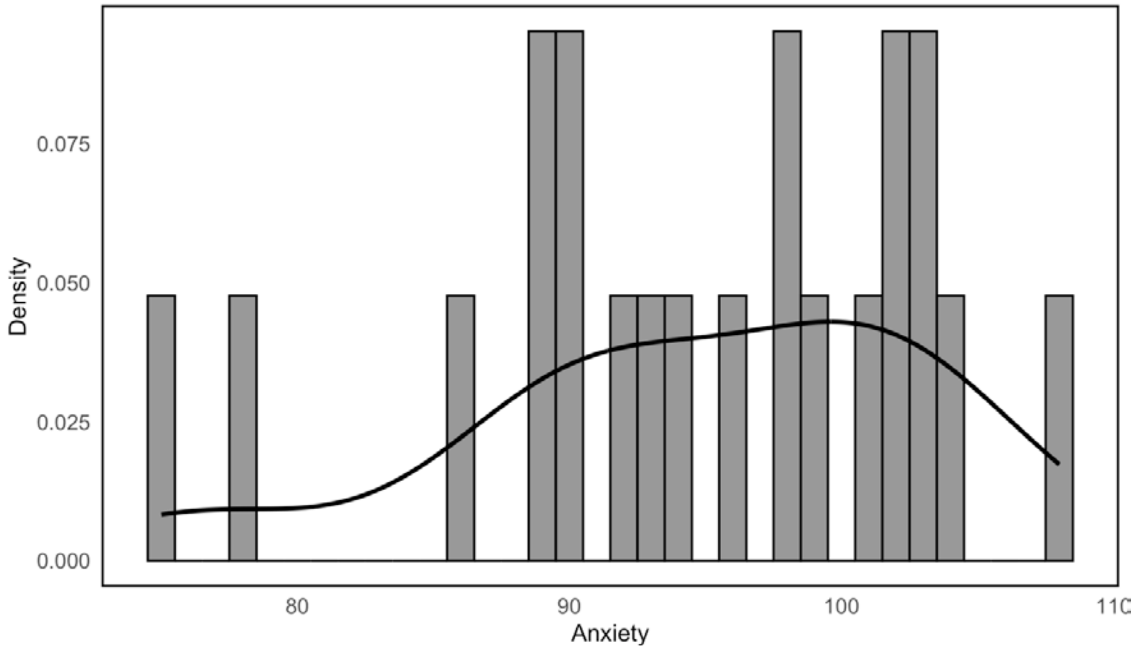
Accuracy across Blocks: Pilot 4



Note: Boxplot showing the accuracy of participants across consecutive trial blocks. Median accuracy for each block is represented by the black line within each box.

Figure 24:

Distribution of State Trait Anxiety Inventory Scores: Pilot 4



Note: This histogram displays the distribution of participants' self-reported anxiety levels, measured by the State-Trait Anxiety Inventory (STAI). The bars represent the density of responses across different levels of anxiety with a bin width of 1, while the density curve provides a smoothed trend line to illustrate the distribution's shape. This figure highlights variations in anxiety scores within the sample.

Discussion:

The manipulation check indicated that participants may not consistently perceive the images as threatening. Although there are observable differences in their responses across conditions, these do not fully align with the intended threat categorization. This suggests a potential issue in the way threat-related stimuli are encoded or interpreted by participants.

One approach to address this might involve a trial-by-trial encoding of neutral versus threatening images, tailored to each participant's subjective threat ratings. By adapting the categorization to individual perceptions, rather than predefined labels, we may obtain a more accurate measure of how perceived threat impacts attentional processes. This would also enable a closer examination of whether these ratings fluctuate based on the subjective experience of each participant, thus providing a more nuanced understanding of threat perception.

Additionally, order effects may have influenced results, as performance appeared to improve across trial blocks. The counterbalancing of trial type and condition, while necessary for control, likely introduces noise into the data due to these effects. To account for this, an appropriate statistical approach would involve using linear mixed-effect models that include block number as a factor. This adjustment would allow us to accurately capture and control for the impact of block order, providing a clearer picture of the true effects at play.

Chapter 6

Methods

Participants

A total of 132 participants were recruited, comprising 115 adult subjects (University of Sydney undergraduate psychology students, 98 identified as Female) and 15 child subjects (ages 5-14 years, 4 identified as Female).

Adult participants were recruited via the university’s undergraduate psychology participant pool. Child participants were recruited through a community-based approach, including outreach in local parks where research assistants established information stations and encouraged parents to consider participation for their children. Additionally, some parents brought their children to the laboratory to participate.

Informed consent was obtained from all adult participants, who received a study information sheet and completed a written consent form. For child participants, parental consent was obtained through a written consent form, and parents received detailed information on the study's purpose and procedures. Child participants provided verbal assent before beginning the study, with periodic reminders throughout to ensure their ongoing willingness to participate.

This study was approved by the University of Sydney's Human Research Ethics Committee (Approval Number: 2017/HE000994).

Power Analysis

A power analysis was performed using G*Power 3 (Faul et al., 2007) to estimate the sample size required for sufficient statistical power. Based on a significance level of $p = .05$ and a target power of 0.9, a sample size of 115 participants in the adult group was determined to be adequate to detect an effect size of Cohen's $d = .54$, as reported by Dudeney et al. (2015). Notably, these effect sizes were derived from a simpler between-group comparison of means. In contrast, the current study employs more complex multivariate regression modeling, which generally requires fewer participants due to its greater statistical power (Nelson & Zaichkowsky, 1988). Thus, we are confident that the sample of 115 participants is sufficient.

However, recruitment challenges limited the child sample to 15 participants, resulting in an underpowered analysis for detecting specific effect sizes. Consequently, analyses in this subgroup will focus on exploring general trends, which may guide future research.

Questionnaire Measures

Demographic information, including age, gender, and dominant hand, was collected from all participants. Anxiety was assessed using age-appropriate measures for each group:

Adults:

The State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983) was used to measure levels of state and trait anxiety in adult participants. The STAI consists of two 20-item subscales that measure trait and state anxiety, with each item rated on a 4-point scale from 1 (not at all) to 4 (very much so). Higher scores indicate higher levels of anxiety. In the present study, scores from the state and trait subscales were combined to create an overall anxiety severity score. This approach provided a more valid comparison to the Revised Children's Manifest Anxiety Scale (RCMAS; Reynolds & Richmond, 2000) used for the child sample, which does not include distinct state and trait subscales like the STAI. Additionally, the subscales of the STAI were also analysed separately to confirm the pattern of results.

Children:

The RCMAS was administered to assess anxiety in the child sample (Reynolds & Richmond, 2000). The RCMAS includes 37 yes-or-no items, with 28 items specifically measuring anxiety across three subscales: physiological anxiety, oversensitivity, and social concern. An additional "lie" subscale assesses social desirability. Each "yes" response is scored as 1, resulting in a total anxiety score from the 28 anxiety-related items. Following recommended guidelines (as per, Reynolds & Richmond, 2000), participants scoring more than two standard deviations above the mean on both the anxiety and social desirability subscales were flagged for potential exclusion, as these scores may indicate inaccurate responding.

Manipulation Check

To assess the effectiveness of the threat manipulation, all distractor stimuli were re-presented individually, and participants were asked to rate how threatening they perceived each stimulus to be. Threat ratings were collected using a Likert scale ranging from 1 (not at all threatening) to 5 (extremely threatening). These ratings allowed for the examination of whether participants consistently perceived the intended differences between neutral and threatening stimuli. These ratings were ultimately used within the analysis of participants trial by trial perceived threat of distractors, as outlined in the data analytic plan. Instructions and an example of this task are shown in Figure 17.

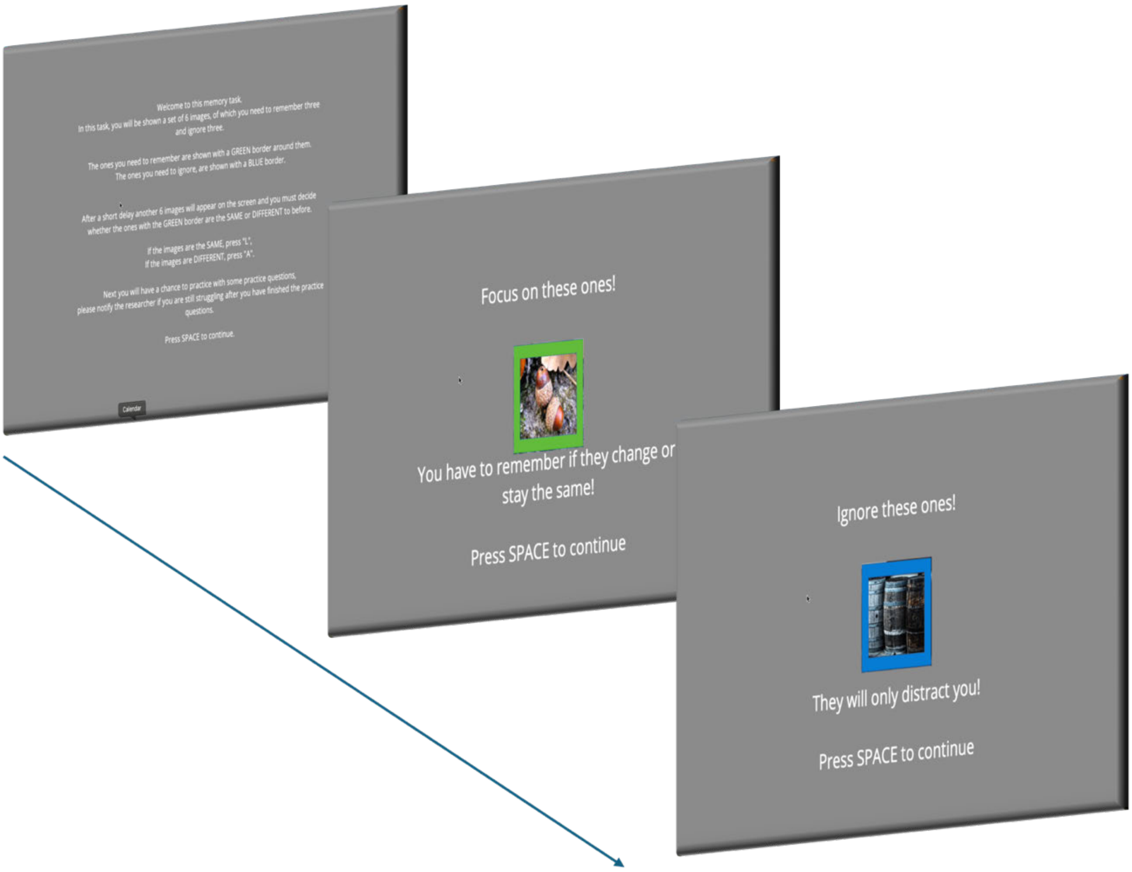
Task Design

Participants began with demographic questions, followed by the appropriate anxiety questionnaire—RCMAS for children and STAI for adults. After completing these measures, participants received instructions for the working memory task.

Each trial began with a central fixation cross that remained on-screen throughout. Participants were first presented with task instructions (see Figure 25) and then completed 12 practice trials, where the array display times began at 2000ms and decreased incrementally by 50ms per trial. This approach aimed to minimize order effects from an abrupt reduction in display time between practice and test. Practice trials were followed by a repeat of the instructions before participants proceeded to the testing phase.

Figure 25:

Task Instructions Displayed to Participants

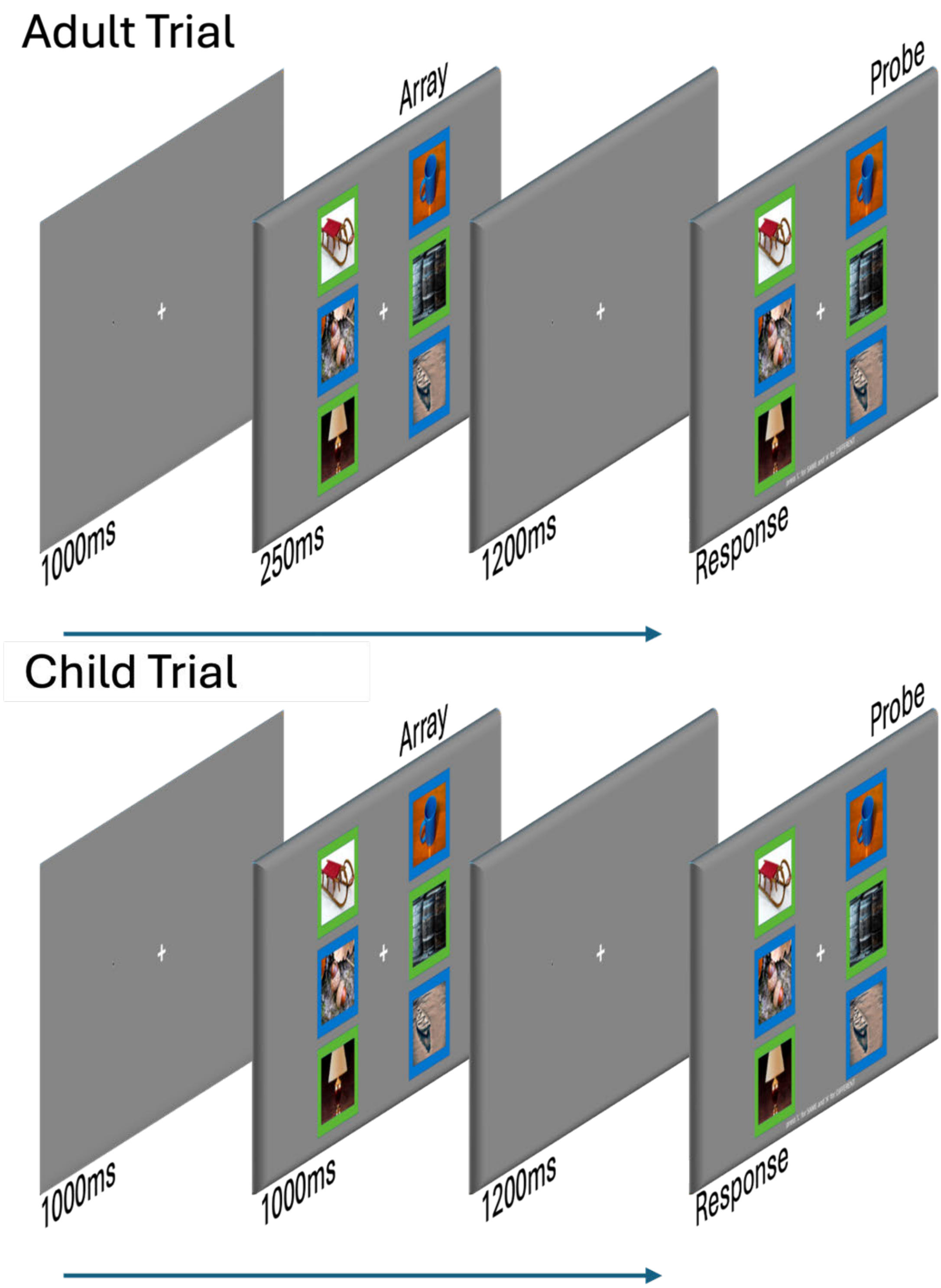


Note: Instructions were presented prior to the start of the behavioural task to ensure participants understood the requirements of attending to and remembering stimuli encircled by the predesignated colour.

Following the fixation cross, a bilateral array of stimuli, each surrounded by a coloured border, appeared on the screen. Participants were instructed to attend to and remember the stimuli encircled by a specific colour (either blue or green, counterbalanced across participants). For the adult version of the task, the initial to-be-remembered array was displayed for 250ms, whereas for the child version, it was displayed for 1000ms. This was followed by a 1200ms retention interval, a probe array reappeared in the same positions as the initial array. Participants were asked to indicate whether any of the stimuli with the cued colour border had changed from the initial presentation. Once a response was given, the next trial commenced. A schematic of adult and child trials is displayed in Figure 26.

Figure 26:

Trial Schematic of the Behavioural Task



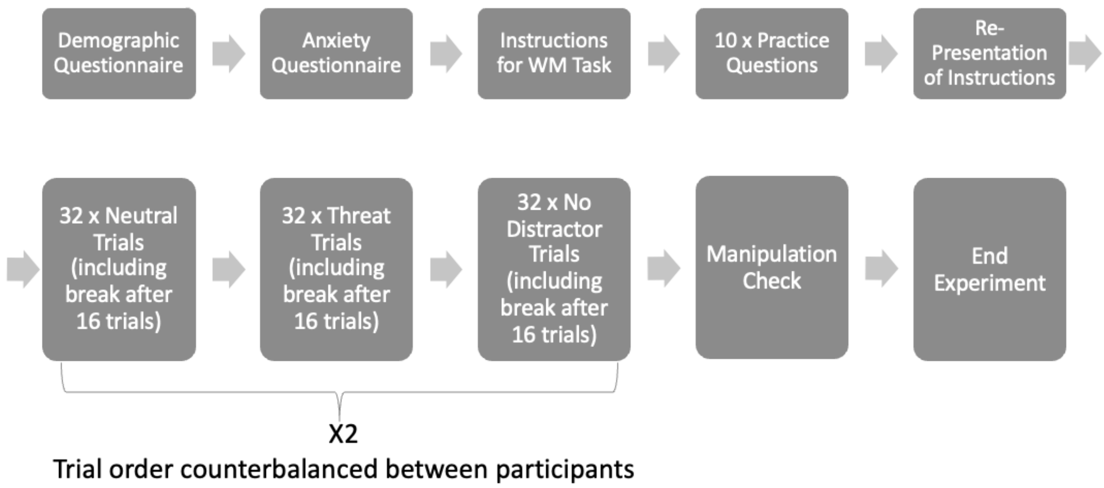
Note: A step-by-step illustration of the sequence for each trial, beginning with the fixation cross, followed by the stimulus array, delay interval, and ending with the probe array.

Adult Task Design:

The adult task consisted of 64 neutral, 64 threat, and 64 no-distractor trials, organized into blocks of 32 trials. Participants were given a break every 16 trials to reduce fatigue (see Figure 27 for an overview of the adult task design). Trial order was counterbalanced across participants to control for order effects. A detailed description of the counterbalancing procedure is provided in Table 2.

Figure 27:

Overview of Adult Task Design



Note: The adult task includes a total of 192 trials (64 neutral, 64 threat, 64 no-distractor), presented in blocks of 32 trials with breaks every 16 trials.

Child Task Design:

Child participants completed a total of 16 neutral, 16 threat, and 16 no-distractor trials, grouped into blocks of 8 trials each. These trials were similarly counterbalanced across participants to control for order effects (see Figure 28 for an overview of the child task design).

Table 2:

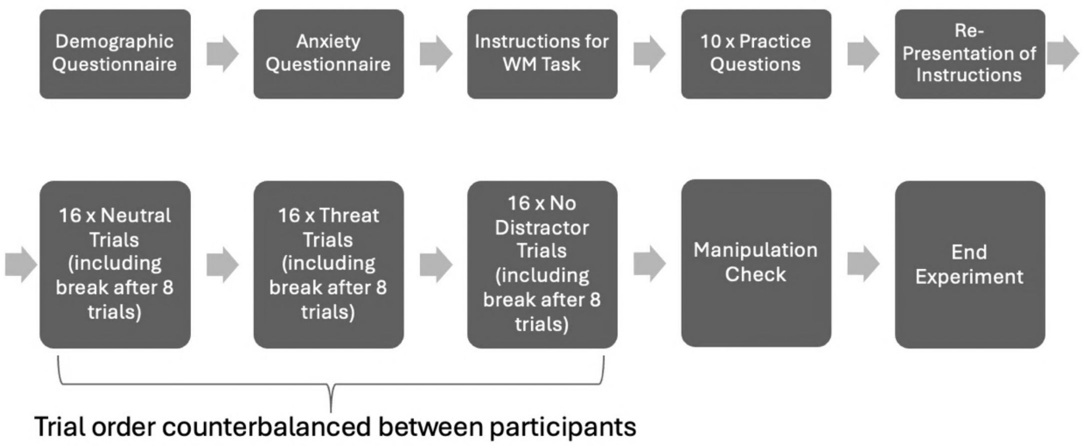
Counterbalancing Procedure

Counterbalancing Condition	Experiment Presentation	Target Colour
1	Neutral → Threat → No Distractor	Green
2	Neutral → No Distractor → Threat	Blue
3	Threat → Neutral → No Distractor	Green
4	Threat → No Distractor → Neutral	Blue
5	No Distractor → Neutral → Threat	Green
6	No Distractor → Threat → Neutral	Blue

Note: A detailed overview of the counterbalancing approach used to control for order effects in the presentation of trial types.

Figure 28:

Overview of Child Task Design



Note: The child task includes a total of 48 trials (16 neutral, 16 threat, 16 no-distractor), presented in blocks of 8 trials with counterbalancing across participants.

Data Storage and Security

Data Storage: All raw data was stored in a secure, password-protected one drive folder accessible only to authorized research personnel. During data collection, data was immediately uploaded to the labs OneDrive to prevent loss.

Data Anonymization: To protect participant confidentiality, each participant was assigned a unique code, replacing identifiable information in all data files. A separate file linking participant codes to identities was securely stored.

Data Analytic Plan

Data Processing and Cleaning:

Data underwent an initial quality check to identify and address outliers, missing values, and potential errors. Trials with response times greater than 3 standard deviations from the median were excluded from analyses of both accuracy and response time outputs, as participants were unlikely to have paid attention at such long intervals, even if they answered correctly. For the response time analyses, incorrect trials were also excluded.

To account for the relative magnitude of anxiety scores compared to performance and response times, anxiety scores were standardized to the mean. Additionally, raw response times were log-transformed when necessary to address skewness. Categorical variables, such as distractor presence and response conflict, were dummy-coded to facilitate model comparisons.

Questionnaire data was merged with task performance data based on participant IDs to ensure consistency and alignment across data types for mixed-effects model analyses. Due to the lack of distinction between perceived threat levels of the “threatening” and “neutral” images, we recoded the images based on participants' subjective threat ratings. Each participant assigned a score from 1 to 5 for how threatening they found each image. Using these scores, we calculated the average threat rating for distractors in each trial. This allows for the calibrated threat level of every trial based on each subject's individual rating. This is critical for mixed-models to capture trial-level variation.

Data Analysis:

We employed linear and generalized linear mixed-effects models to explore the effects of experimental conditions (e.g., distractor condition, perceived threat, response conflict) and anxiety levels on response time and accuracy. Each model included random intercepts for participants and blocks to account for the repeated-measures design. All analyses were conducted using R (version 2023.06.0+421) with specific packages such as lme4 for mixed-effects modelling.

Documentation of the code for data cleaning, preprocessing, and statistical analyses was maintained to ensure transparency and reproducibility throughout the research process which is available at Open Science Framework:

A New Cognitive Paradigm for Measuring Attentional Control and Attentional Bias in Children and Adults. Retrieved from: https://osf.io/x932p/?view_only=f461792577fa469a8709d1bdddf41fcb

Chapter 7

Results

The primary objective of this study was to investigate how attentional control and attentional bias are associated with anxiety in a child and adult sample. Specifically, we examined the impact of distractor presence and response conflict of outcome on task performance, as well as whether anxiety moderated these effects. We also explored how variations in perceived threat of distractor items impacted task performance and the role which anxiety plays in this effect. Linear mixed-effect models and generalized linear mixed-effect models were employed to analyse response time and accuracy data, respectively, allowing for the inclusion of random effects for participants and trial blocks. The following section presents the findings from these analyses, focusing on the main effects and interactions of interest.

Adult Sample

Descriptive Statistics

Participants' overall mean accuracy was .77 (SD = .093), and mean response time was 123.1ms (SD = .386). Accuracy was higher in the no distractor condition (M = .820, SD = .005) compared to the distractor condition (M = .738, SD = .004), suggesting that the presence of distractors reduced performance accuracy.

Similarly, response times increased in the presence of distractors. The mean response time was 1114.8ms (SD = .861) in the no distractor condition, compared to 1220.2ms (SD = .701) with distractors, indicating that distractors led to slower response times.

Perceived Threat of Distractors

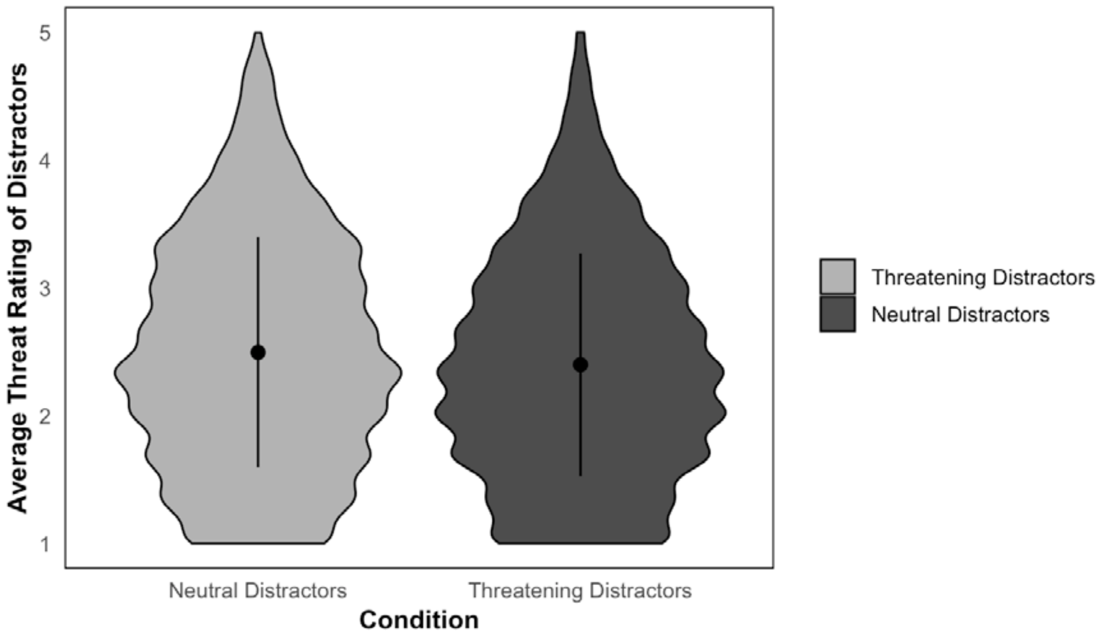
Valence ratings for distractor images showed minimal difference in perceived threat between the two categories. On a 1–5 Likert scale, where 1 is of ow perceived threat and 5 is highly threatening, images previously categorized as "neutral" had a mean threat rating of 2.50 (SD = .90), while "threatening" images had a mean rating of 2.40 (SD = .87) (Figure 29). This lack of differentiation in perceived threat justifies the use of individual subjective ratings at a trial-by-trial level for further analyses. Ranked average ratings of each distractor image is presented in Figure 30.

Anxiety Scores

STAI results indicated that participants had a mean total score of 93.557 (SD = 8.443), with the state anxiety subscale mean of 43.852 (SD = 4.769) and the trait anxiety subscale mean of 49.704 (SD = 5.826). The combined and trait subscale scores indicate a high level of anxiety, whereas the state anxiety subscale reflects moderate anxiety levels, consistent with the categorization guidelines for STAI scores (Kayikcioglu et al., 2017; see Figure 31).

Figure 29:

Distribution of Subjective Image Threat Ratings Across Distractor Pre-Coded Condition



Note: This figure shows the distribution of average threat ratings for distractor images categorized as "Neutral" and "Threatening." The ratings were based on participants' subjective assessments on a 1-5 Likert scale, with higher values indicating a greater perceived threat.

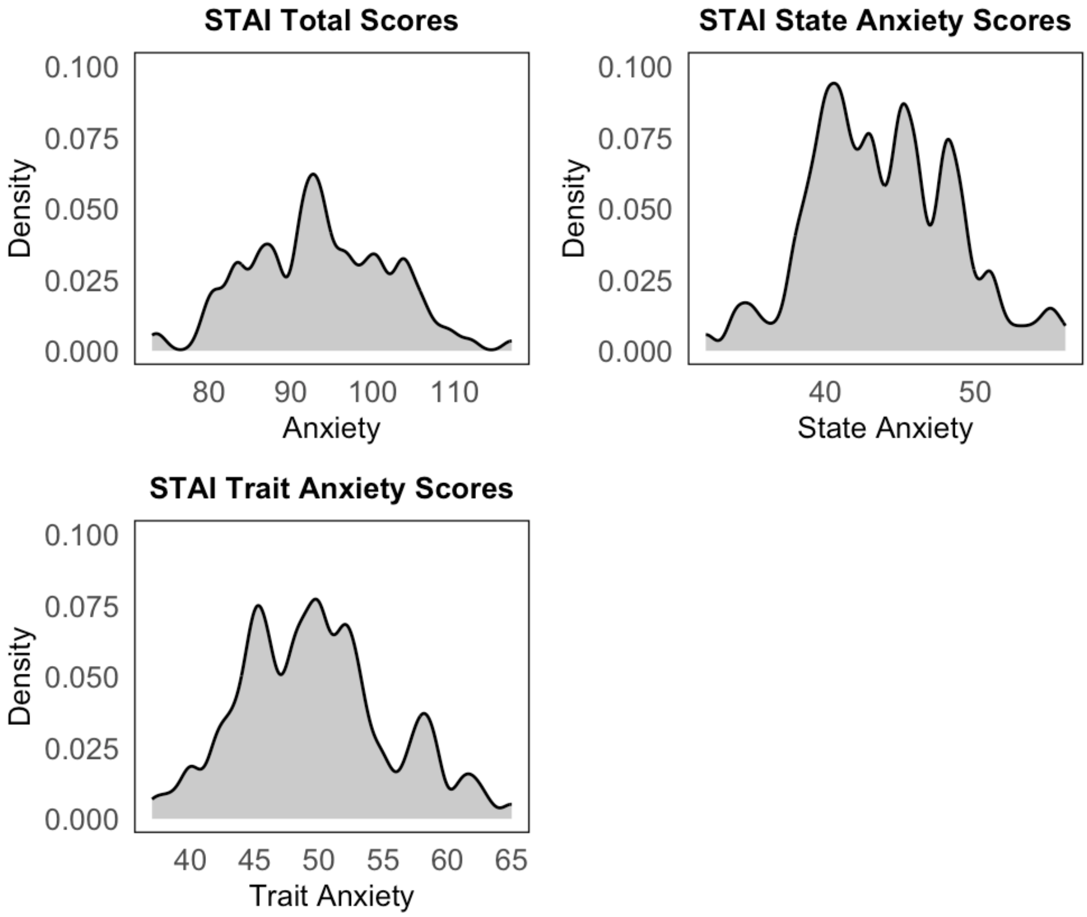
Figure 30:

Mean Normalised Threat Ratings of Distractor Images

Note: Overall threat ratings for each distractor image, as rated by participants after completing the task. Points represent mean normalised threat ratings, with error bars indicating the standard deviation of the mean. Each image is displayed beneath its corresponding mean score with its overall average ranking.

Figure 31:

Distributions of STAI Total, State, and Trait Scores



Note: This figure presents density distributions for the State-Trait Anxiety Inventory (STAI) scores across three dimensions: Total Anxiety, State Anxiety, and Trait Anxiety. Scores reflect participants' self-reported anxiety levels, with higher values indicating greater anxiety. The Total Anxiety score combines both State and Trait subscales.

Linear Mixed-Effects Model Analysis

We used linear mixed-effect models to examine the impact of response conflict, distractor presence, and perceived threat on response time and accuracy. Each model included random intercepts for participants and block number to control for individual differences and trial order effects.

Outcome of Models:

Six mixed-effect models were constructed to address the key research questions. Models 1, 3, and 5 examined accuracy, while Models 2, 4, and 6 examined response time. Models 1 and 2 assessed whether the presence of distractors significantly impacted performance through the main effect of distractor presence on accuracy or response time. Models 3 and 4 examined whether performance was higher on non-conflict trials compared to conflict trials by analysing the main effect of response conflict on performance. The interaction terms of response conflict and anxiety (models 3 and 4), as well as distractor presence and anxiety (models 1 and 2), addressed whether individuals with higher anxiety exhibit deficits in attentional control. The main effect of distractor perceived threat on performance in Models 5 (accuracy) and 6 (response time) addressed whether individuals generally find it harder to ignore distractors perceived as threatening. Additionally, the interaction term between distractor perceived threat and anxiety in these models explored whether participants with higher anxiety display a greater attentional bias toward threat compared to those with lower anxiety.

Model 1:

Generalized Linear Mixed-Effects Model: Distractor Presence and Anxiety ~ Accuracy

A generalized linear mixed-effects model (GLMM) with a binomial logit link function was conducted to investigate the effects of distractor condition, anxiety, and their interaction on accuracy. Random intercepts were included for both subjects and blocks to account for repeated measures. The model was fitted using maximum likelihood estimation (Laplace Approximation).

The model fit was evaluated using the Akaike Information Criterion (AIC = 22,710) and the Bayesian Information Criterion (BIC = 22,758). Scaled residuals indicated acceptable fit, with a median of 0.46 and values ranging from -4.06 to 1.09.

Random Effects

Random intercept variance for subjects was moderate (SD = 0.52), indicating between-subject variability in accuracy, while the variance for blocks was smaller (SD = 0.07), suggesting less variability between blocks.

Fixed Effects

The fixed effects for distractor condition, anxiety, and their interaction are summarized in Table 3:

Table 3:

Summary of Mixed-Effect Model 1 Predicting Accuracy

Predictor	Estimate	Odds Ratio	Std. Error	z-value	p-value
Intercept	1.10	3.00	0.06	18.26	< 0.01***
Distractor Condition (No Distractor)	0.5	1.65	0.04	13.70	< 0.01***
Anxiety	0.05	1.05	0.05	0.96	0.34
Distractor Condition × Anxiety Interaction	0.03	1.03	0.04	0.88	0.38

Summary of Findings

There was a significant effect of distractor condition, with higher accuracy in the "No Distractor" condition compared to the "Distractor" condition. This corresponds to a higher probability of correct responses in trials without distractors.

The main effect of anxiety on accuracy was not significant, indicating that anxiety did not significantly influence accuracy.

The interaction between distractor condition and anxiety was also not significant, suggesting that the effect of distractor condition on accuracy was not moderated by anxiety.

These findings suggest that whilst distractors impair performance, anxiety does not moderate this effect.

Model 2:

Linear Mixed-Effects Model: Distractor Presence and Anxiety ~ Response time

A linear mixed-effects model was conducted to examine the effects of distractor condition, anxiety, and their interaction on response time. The model included random intercepts for both subjects and blocks, accounting for repeated measures. The model was fitted using Restricted Maximum Likelihood (REML).

The model's fit, as indicated by the REML criterion, was 29,870.9. Scaled residuals showed a median of -0.23, with a minimum of -3.58 and a maximum of 6.09, suggesting some variance in residuals but no extreme deviations that would indicate substantial model misfit.

Random Effects

Random effects indicated moderate variability across subjects (SD = 0.38) and blocks (SD = 0.15). The residual variance was 0.34 (SD = 0.59), indicating moderate variability in response times that was not explained by the fixed effects or random effects.

Fixed Effects

The fixed effects estimates are reported in Table 4:

Table 4:
Summary of Mixed Effect Model 2 Predicting Response Time

Predictor	Estimate	Std. Error	t-value	p-value
Intercept	1.41	0.40	3.52***	<.01
Distractor Condition (No Distractor vs. Distractor)	-0.20	0.11	-1.84	.07
Anxiety	-0.001	0.004	-0.46	.65

Predictor	Estimate	Std. Error	t-value	p-value
Distractor Condition × Anxiety Interaction	0.0008	0.001	0.73	.47

Summary of Findings

The effect of distractor condition on response time approached significance. This suggests a trend where response times were shorter in the "No Distractor" condition compared to the "Distractor" condition.

The main effect of anxiety on response time was not significant, indicating that anxiety did not meaningfully affect response time.

The interaction between distractor condition and anxiety was also not significant, suggesting that the effect of distractor condition on response time did not vary as a function of anxiety levels.

Model 3:

Generalized Linear Mixed-Effects Model: Response Conflict and Anxiety ~ Accuracy

A generalized linear mixed-effects model was used to analyse the effects of response conflict, anxiety, and their interaction on accuracy, using a binomial (logit) link function. The model included a random intercept for subjects to account for the repeated measures nature of the data.

The model fit statistics were as follows: AIC = 15,958.4, BIC = 16,003.8, and log-likelihood = -7,973.2. Scaled residuals indicated a reasonable distribution, with a median value of 0.51 and extremes ranging from -3.65 to 1.02.

Random Effects

There was moderate variability in accuracy between subjects, as indicated by the random intercept variance (Variance = 0.271, SD = 0.52), suggesting individual differences in baseline accuracy.

Fixed Effects

The fixed effects estimates are reported in Table 5:

Table 5:

Summary of Mixed Effect Model 3 Predicting Accuracy

Predictor	Estimate	Odds Ratio	Std. Error	z-value	p-value
Intercept	0.926	2.52	0.069	13.33	< .01**
Response Conflict	0.097	1.1	0.039	2.49	.013*
Anxiety	0.039	1.04	0.056	0.70	.49
Block Number	0.034	1.03	0.012	2.86	<.01**
Response Conflict × Anxiety Interaction	0.024	1.02	0.039	0.63	.53

Summary of Findings

The effect of response conflict was significant. Participants were more likely to be accurate in non-conflict trials compared to conflict trials.

The main effect of anxiety was not significant, suggesting that anxiety did not directly influence accuracy.

Block number had a significant positive effect on accuracy, indicating that participants' accuracy improved as they progressed through the experiment.

The interaction between response conflict and anxiety was not significant, indicating that the effect of response conflict on accuracy did not depend on participants' anxiety levels.

Model 4:

Linear Mixed-Effects Model: Response Conflict and Anxiety ~ Response time

A linear mixed-effects model was conducted to examine the effects of response conflict, anxiety, and their interaction on response time. Random intercepts were included for both subjects and blocks to account for the repeated measures structure of the data. The model was fitted using Restricted Maximum Likelihood (REML).

The model's fit, as indicated by the REML criterion, was 19,600.5. The scaled residuals showed a median of -0.233, with a minimum of -3.06 and a maximum of 5.90, indicating some spread but no extreme deviations that would suggest model misfit.

Random Effects

The random effects indicated substantial variability across subjects (SD = 0.38) and blocks (SD = 0.16). The residual variance was 0.36 (SD = 0.60), indicating moderate variability in response times that was not explained by the fixed effects or the random effects.

Fixed Effects

The fixed effects of the model are shown in Table 6:

Table 6:

Summary of Mixed Effect Model 4 Predicting Response Time

Predictor	Estimate	Std. Error	t-value	p-value
Intercept	1.38	0.41	3.33*	<.01**
Response Conflict	0.01	0.13	0.07	.94
Anxiety	-0.0015	0.0044	-0.35	.73
Response Conflict × Anxiety Interaction	-0.0002	0.0014	-0.15	.88

Summary of Findings

In summary, this model suggests no significant main or interaction effects of response conflict and anxiety on response time. Response times did not vary significantly between conflict and non-conflict trials, nor did anxiety level affect response time or modulate the effect of response conflict.

Model 5:

Generalized Linear Mixed-Effects Model: Perceived Threat and Anxiety ~ Accuracy

A generalized linear mixed-effects model (GLMM) with a binomial distribution and logit link function was used to analyse the effect of perceived threat, anxiety, and their interaction on accuracy. The model included random intercepts for subjects and blocks to account for the repeated measures design and was fitted using maximum likelihood estimation with the Laplace approximation.

The model's fit was evaluated using AIC (16,045.5) and BIC (16,091.0), with a log-likelihood of -8,016.8.

Random Effects

The random effects modelled variability across subjects and blocks, with the following estimates:

Subject-level variance: 0.282 (SD = 0.531), suggesting moderate variability in accuracy across participants.

Block-level variance: 0.006 (SD = 0.080), indicating low variability across blocks.

Fixed Effects

The fixed effects for image valence, anxiety, and their interaction are summarized in Table 7:

Table 7:

Summary of Mixed Effect Model 5 Predicting Accuracy

Predictor	Estimate	Odds Ratio	Std. Error	z-value	p-value
Intercept	1.142	3.13	0.092	12.44	< 0.01**
Perceived Threat (Standardized)	-0.020	0.98	0.027	-0.72	0.47
Anxiety	-0.142	0.87	0.087	-1.64	0.10
Perceived Threat × Anxiety Interaction	0.082	1.09	0.029	2.81	< 0.01 **

Summary of Findings

The effect of perceived threat on accuracy was not significant, indicating no substantial difference in performance across varying levels of perceived threat.

The main effect of anxiety was not significant, suggesting there was no variation in accuracy across different levels of anxiety.

The interaction between perceived threat and anxiety was significant, indicating that the relationship between perceived threat and accuracy was moderated by anxiety. For individuals with low anxiety (1 SD below the mean on the STAI), the simple slope was -0.10, suggesting that as perceived threat increased, performance decreased. In contrast, for individuals with high anxiety (1 SD above the mean), the simple slope was 0.06, indicating that as perceived threat increased, performance also increased.

Model 6:

Linear Mixed-Effects Model: Perceived Threat and Anxiety ~ Response Time

A linear mixed-effects model (LMM) was used to examine the effects of perceived threat, anxiety, and their interaction on response time. The model included random intercepts for subjects and blocks, accounting for the repeated measures design, and was fitted using restricted maximum likelihood (REML).

The model fit was evaluated using the REML criterion (19,899.5). Scaled residuals indicated a reasonable fit to the data, with a median of -0.23 and residuals ranging from -3.08 to 5.90.

Random Effects

Random intercepts were included for subjects and blocks, with a variance of 0.145 (SD = 0.38) for subjects and 0.025 (SD = 0.16) for blocks, indicating more variability between subjects than between blocks.

Fixed Effects

The fixed effects for perceived threat, anxiety, and their interaction are summarized in Table 8:

Table 8:
Summary of Mixed Effect Model 6 Predicting Response Time

Predictor	Estimate	Std. Error	t-value	p-value
Intercept	1.25	0.48	2.61	0.01 **
Perceived Threat (Standardized)	0.06	0.11	0.52	0.60
Anxiety	0.0003	0.005	0.05	0.96
Perceived Threat × Anxiety Interaction	-0.0007	0.001	-0.66	0.51

Summary of Findings

In this model, neither perceived threat nor anxiety had significant effects on response time, and the interaction between these variables was also non-significant. This suggests that response time was not meaningfully influenced by the perceived threat of the images or by participants' anxiety levels in this task. The interaction between perceived threat and anxiety was also non-significant, indicating that the effect of perceived threat on response time did not depend on anxiety levels.

Summary of Results (Adult Sample)

In this study, participants were assessed on their response times and performance across conditions with varying distractor presence and perceived threat levels. We found no significant differences in response times across any conditions, suggesting that accuracy may have been substituted for response speed.

The study investigated several hypotheses to explore the impact of attentional control demands and anxiety on task performance. **Hypothesis 1a** posited that participants would exhibit decreased performance when distractors were present. This was supported by a significant main effect of distractor presence ($p < .01$), as illustrated in Figure 32, with participants demonstrating lower accuracy when distractors were present.

Similarly, **Hypothesis 1b** predicted that participants would perform better on non-conflict trials compared to conflict trials. The results confirmed this prediction, with significantly lower performance observed on conflict trials. This further underscores the role of attentional control demands in modulating task performance.

Hypothesis 2a anticipated an interaction between distractor presence and anxiety levels, such that participants with higher anxiety would show a more pronounced decline in performance when distractors were present. Contrary to expectations, no such interaction was observed ($p = .167$; Figure 33). These findings suggest that attentional control in the presence of distractors does not differ across anxiety levels, challenging prior self-report-based studies that indicated anxiety impairs attentional control.

Further, **Hypothesis 2b** posited an interaction between response conflict and anxiety, predicting greater performance declines for conflict trials among participants with higher anxiety. However, the results revealed no significant interaction between response conflict and anxiety. This further supports the conclusion that attentional control remains consistent across varying anxiety levels, as evidenced by similar performance patterns regardless of the presence of distractors or conflict demands.

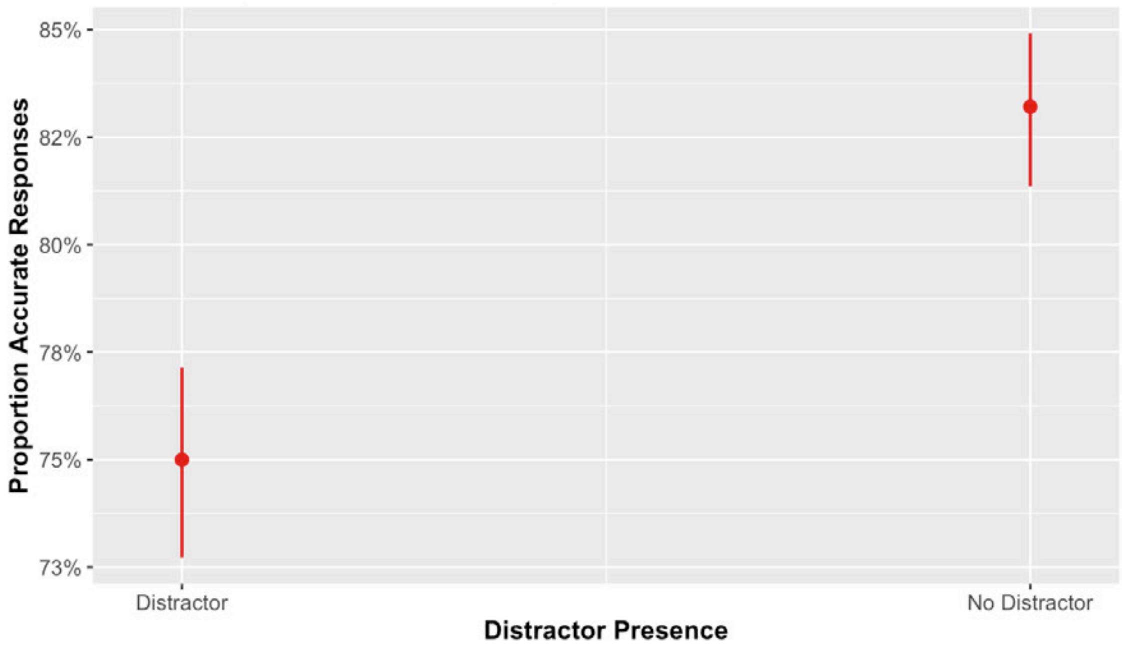
Hypothesis 3 predicted a significant decrease in performance as the perceived threat of distractors increased. However, no main effect of perceived threat on performance was found ($p=.47$; Figure 34), suggesting that variations in the perceived threat of distractors did not directly impact accuracy.

Further, **Hypothesis 4** posited that individuals with higher anxiety levels would demonstrate a stronger attentional bias toward threatening stimuli, leading to decreased performance in threatening trials compared to non-anxious participants. The results revealed a significant interaction between perceived threat and anxiety ($p < .01$), though the direction of the effect was contrary to the original hypothesis. As illustrated in Figure 35, individuals with higher anxiety levels unexpectedly demonstrated better performance in high-threat conditions compared to low-threat conditions.

These findings provide insight into the complex relationship between anxiety and attentional control, highlighting the importance of task-based assessments in understanding attentional biases and control under different emotional conditions.

Figure 32:

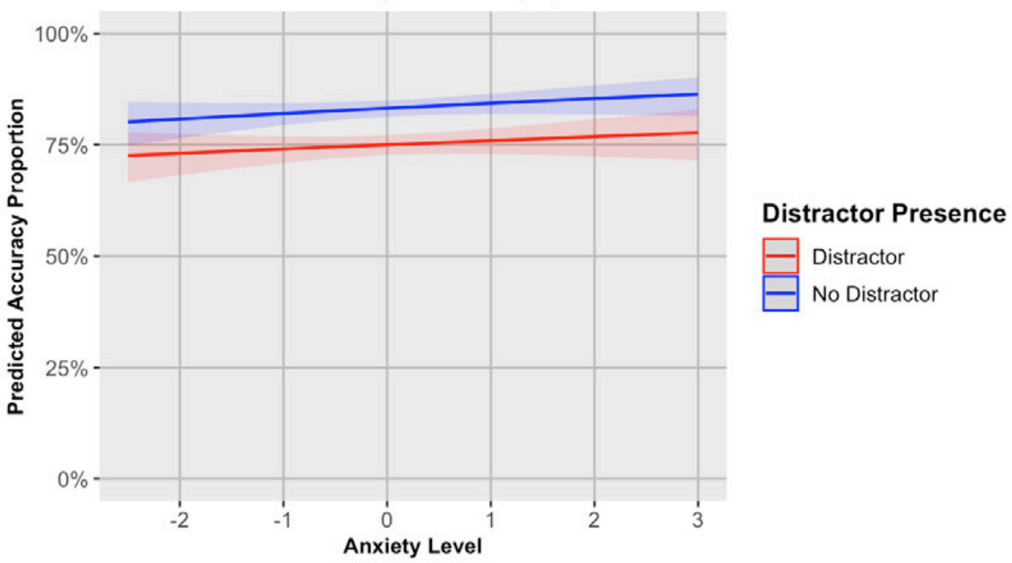
Proportion of Accurate Responses as a Function of Distractor Presence



Note: The displayed values represent the proportion of correct responses for each distractor condition, with error bars indicating standard errors.

Figure 33:

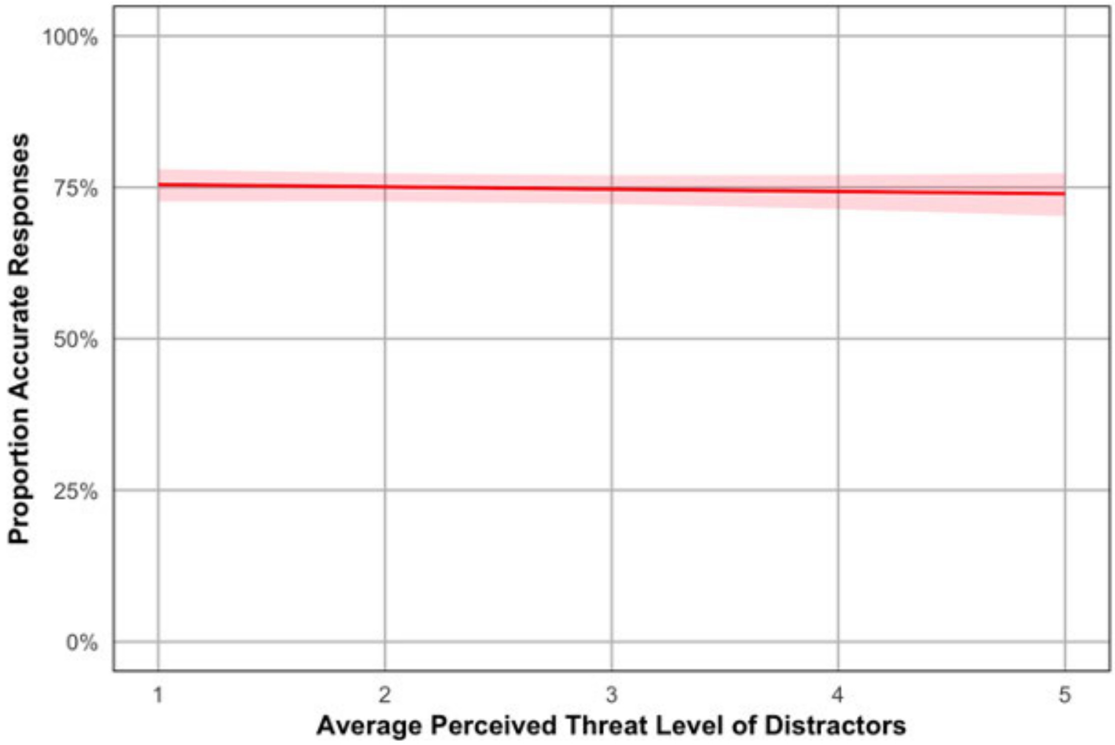
Interaction Between Anxiety Levels and Distractor Presence on Accuracy Proportion



Note: This interaction plot displays the predicted accuracy proportions as a function of normalised anxiety levels and distractor presence. The coloured lines represent different distractor conditions (red for present, blue for absent), illustrating how the accuracy of responses varies with anxiety levels. The y-axis reflects the predicted proportion of accurate responses, with error margins indicating the model's uncertainty.

Figure 34:

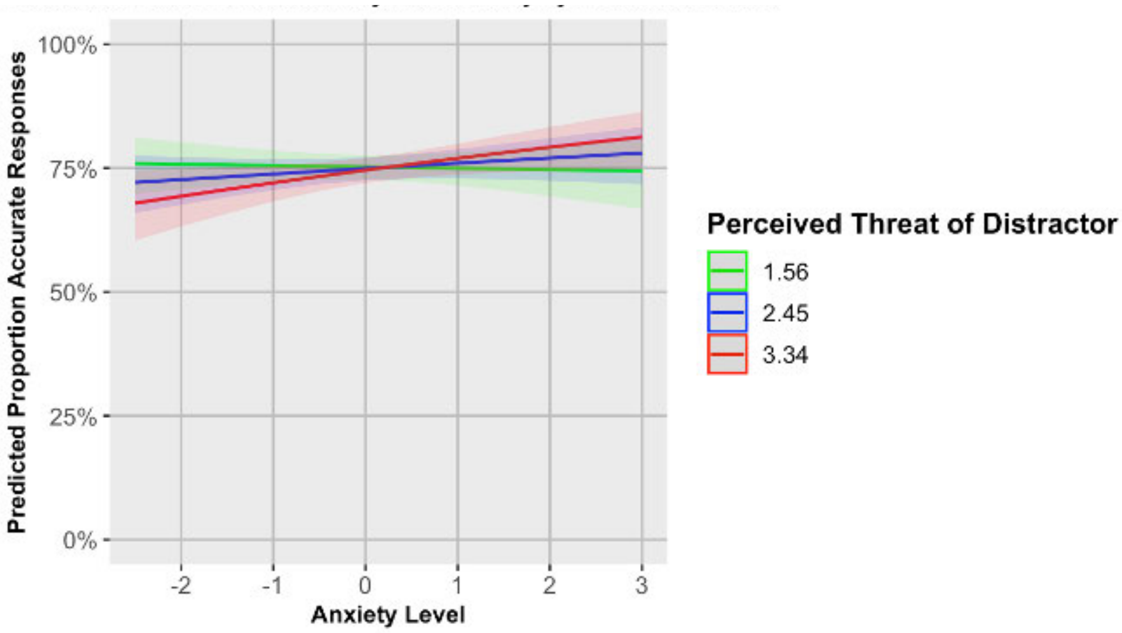
Impact of Perceived Threat Level of Distractors on Accuracy Proportion



Note: This plot illustrates the relationship between the average perceived threat level of distractors and the proportion of accurate responses. The x-axis represents the perceived threat level, while the y-axis indicates the predicted proportion of accurate responses.

Figure 35:

Interaction of Anxiety and Perceived Threat Level on Accuracy Proportion



Note: The x-axis indicates varying levels of normalised anxiety scores, while the y-axis shows the predicted proportion of accurate responses. Different colours represent different levels of perceived threat, with blue representing the mean perceived threat of distractor stimuli, green 1sd below the mean and red 1sd above the mean.

Child Sample

Descriptive Statistics

Ages ranged from 5 to 14 years among the 15 participants comprising the child sample, with the distribution of ages displayed in Figure 36.

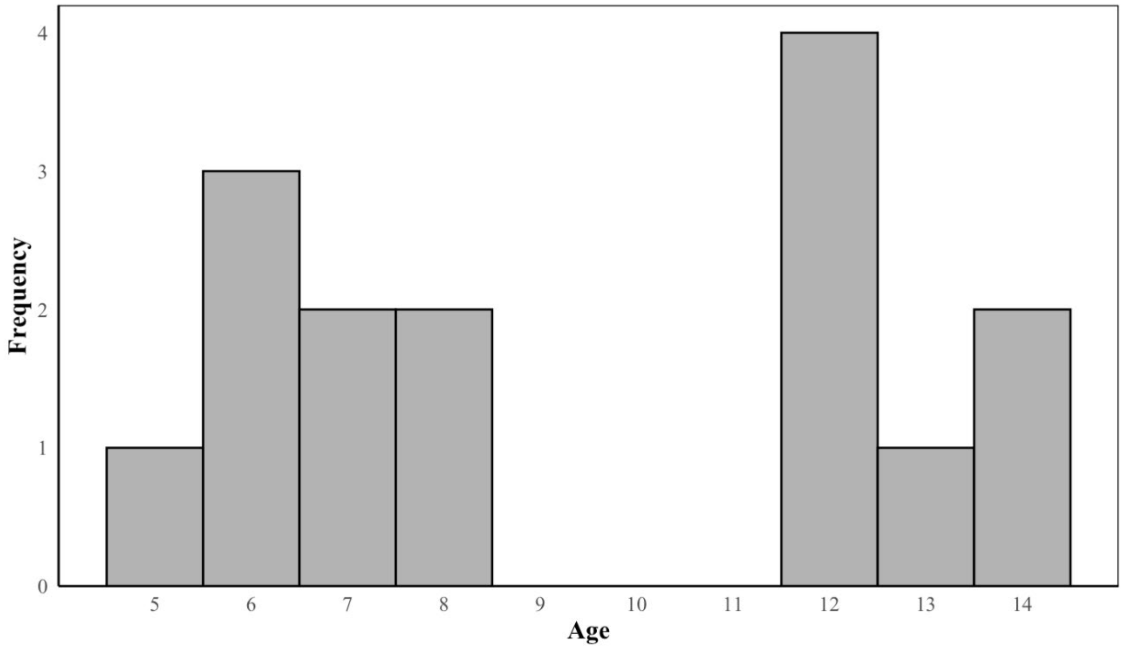
The mean accuracy and response times were calculated for both distractor and no-distractor conditions. Accuracy was lower in the presence of distractors (M = 0.67, SE = 0.02) compared to the no-distractor condition (M = 0.73, SE = 0.03). Mean response times were slower with distractors (M = 2.55 seconds, SE = 0.09) relative to no distractors (M = 2.17 seconds, SE = 0.10). These results suggest that distractors had a noticeable effect on both accuracy and response times, likely requiring the recruitment of attentional control abilities for successful task completion. These effects are visually represented in Figures 39 and 40, with Figure 37 showing accuracy and Figure 38 illustrating response times.

The mean subjective threat ratings for trials involving neutral distractors (M = 2.21, SD = 1.04) and threatening distractors (M = 2.04, SD = 0.90) were similar. As in the adult study, despite the varied threat level of these stimuli on the IAPS, children did not perceive the images as significantly different in threatening nature. These findings support the use of subjective threat ratings in subsequent analyses, as individual ratings provide a more reliable measure of threat perception. Figure 39 shows the mean threat ratings across neutral and threatening conditions. Whilst Figure 40 displays the mean normalised threat ratings for each image.

Anxiety severity was measured with the Revised Children's Manifest Anxiety Scale (RCMAS). The RCMAS consists of 37 items, including a 9-item "lie" subscale for detecting social desirability that may affect accuracy. No participants scored more than 2 SD above the mean on both the anxiety and lie subscales, so no exclusions were made based on inaccurate responses. The mean anxiety score was 15 (SD = 5.51), with scores over 19 indicating clinical levels. Figure 41 shows the distribution of anxiety scores.

Figure 36:

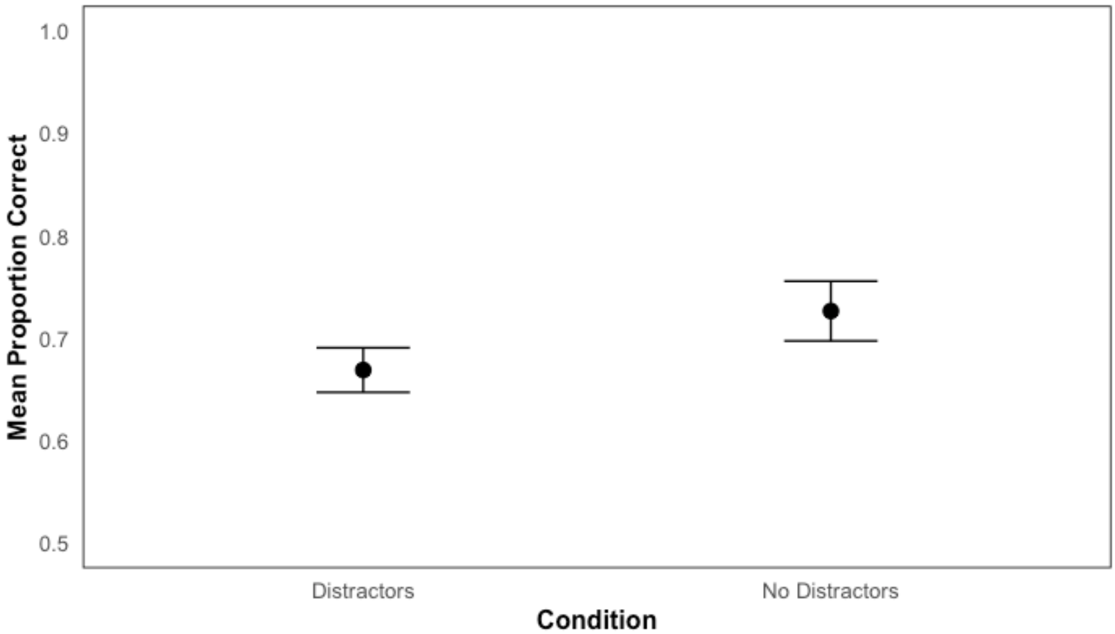
Distribution of Ages in the Child Sample



Note: This histogram illustrates the age distribution across participants in the sample (N = 15). Bins are set to 1-year intervals to display each age group's frequency.

Figure 37:

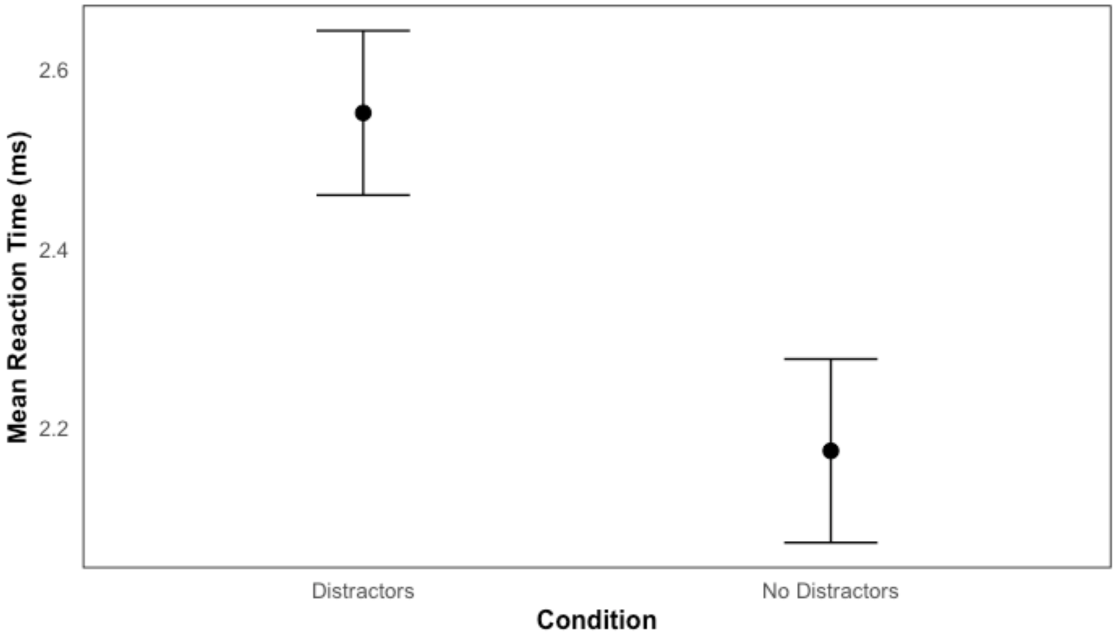
Mean Proportion Correct Across Distractor Conditions – Child Study



Note: Error bars represent the standard error of the mean. The y-axis is scaled from 0.5 to 1 to enhance visibility of differences between conditions. While individual trial scores range from 0 (incorrect) to 1 (correct), overall proportions fall between 0.5 (chance) and 1.

Figure 38:

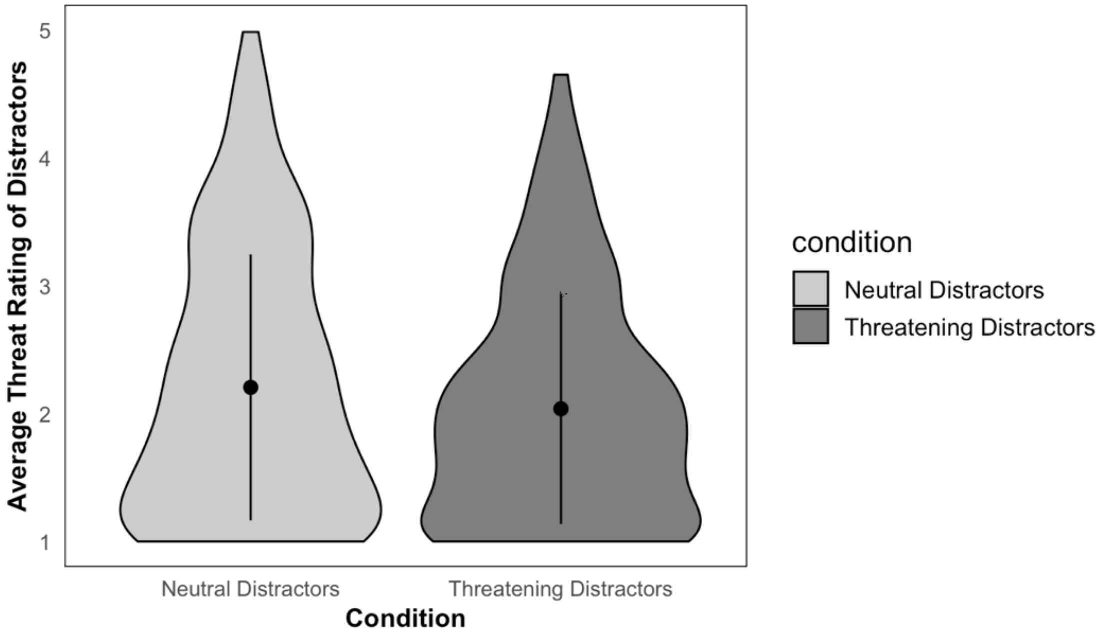
Mean Response time Across Distractor Condition – Child Study



Note: This figure illustrates the mean response time across trials in milliseconds for the child sample in the no distractor and distractor conditions. Error bars represent the standard error of the mean.

Figure 39:

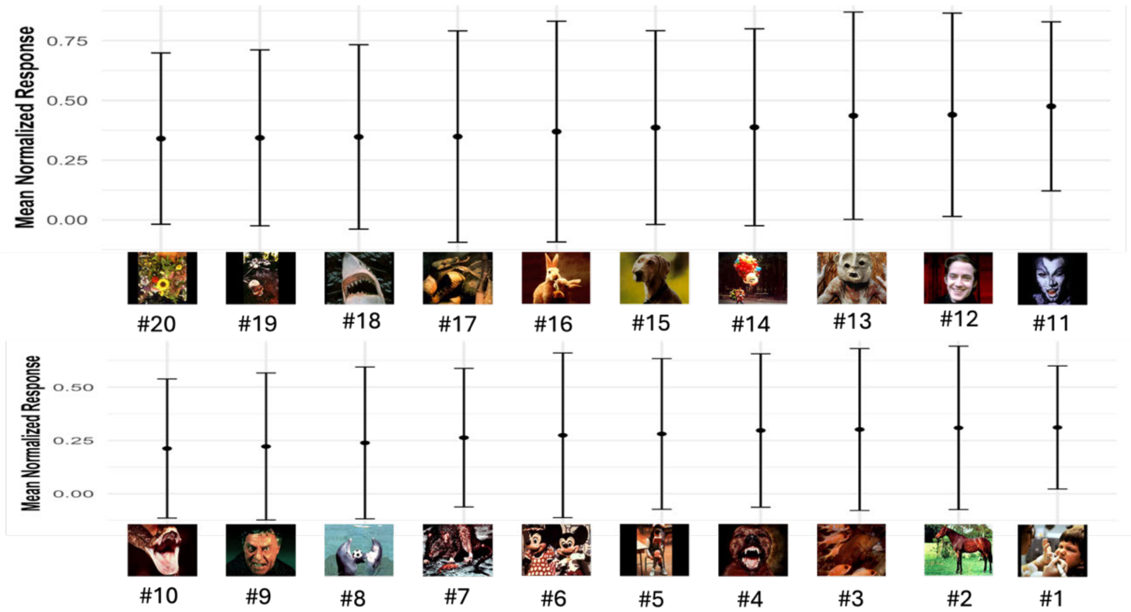
Distribution of Subjective Image Threat Ratings Across Distractor Pre-Coded Conditions – Child Study



Note: This figure shows the distribution of average threat ratings for distractor images categorized as "Neutral" and "Threatening." The ratings were based on child participants' subjective assessments on a 1-5 Likert scale, with higher values indicating a greater perceived threat.

Figure 40:

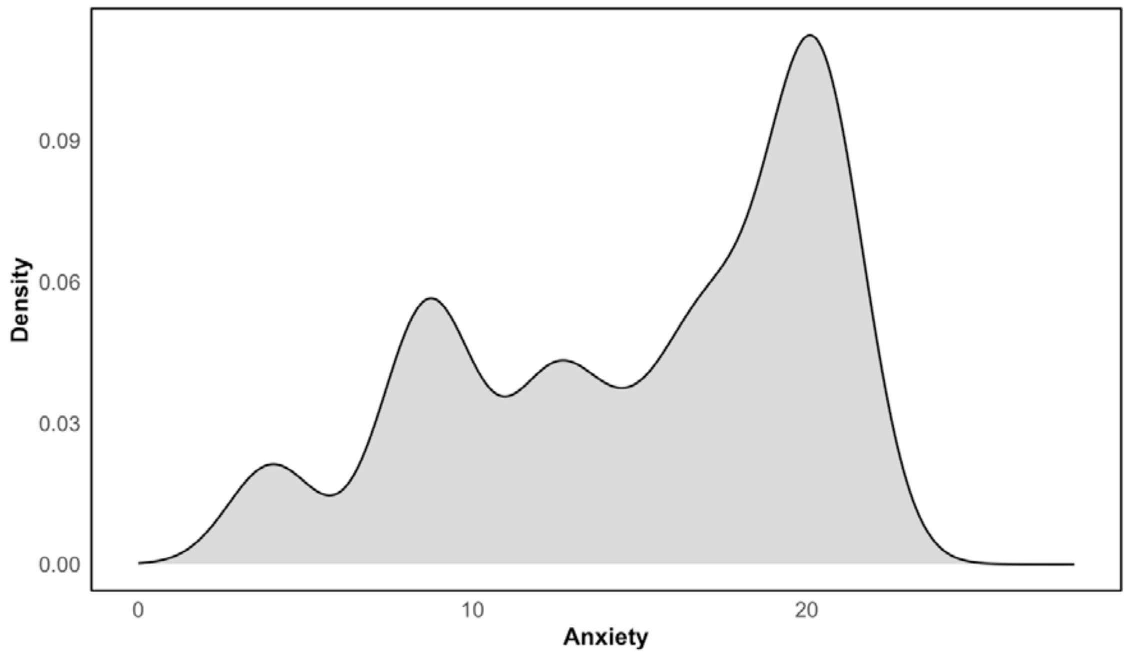
Mean Normalised Threat Ratings of Distractor Images (Child Sample)



Note: Overall threat ratings for each distractor image, as rated by children after completing the task. Points represent mean normalised threat ratings, with error bars indicating the standard deviation of the mean. Each image is displayed beneath its corresponding mean score with its overall average ranking, 20 being least threatening and 1 being most.

Figure 41:

Distribution of RCMAS Total Anxiety Scores



Note: This figure presents the density distribution of scores on the revised children manifest anxiety scale (RCMAS). Scores from the 37-item scale were calculated based on number of total "yes" responses on the 28 anxiety related items, hence anxiety score range from 0-28. Higher scores indicate greater anxiety.

Linear Mixed Effect Models

As in the adult study, linear mixed-effect models were used to examine the effects of predictors on response time and accuracy. The models included random intercepts for participants and block numbers.

Outcome of Models:

Six mixed-effects models were constructed to address the key research questions in the child sample. Models 1, 3, and 5 focused on accuracy, while Models 2, 4, and 6 focused on response time. Models 1 and 2 assessed whether the presence of distractors significantly impacted performance through the main effect of distractor presence on accuracy or response time. Models 3 and 4 evaluated whether performance was higher on non-conflict trials compared to conflict trials by examining the main effect of response conflict on performance. The interaction terms of response conflict and anxiety (Models 3 and 4), as well as distractor presence and anxiety (Models 1 and 2), explored whether children with higher anxiety exhibit deficits in attentional control. The main effect of distractor perceived threat on performance in Models 5 (accuracy) and 6 (response time) examined whether children generally find it more challenging to ignore distractors perceived as threatening. Furthermore, the interaction between distractor perceived threat and anxiety in these models investigated whether children with higher anxiety display a greater attentional bias toward threat compared to those with lower anxiety.

Model 1 (Child Sample):

Generalized Linear Mixed-Effects Model: Distractor Presence and Anxiety ~ Accuracy

A generalized linear mixed model (GLMM) was conducted to examine the effects of distractor condition, anxiety, and their interaction on accuracy. The model included random intercepts for subjects and blocks, accounting for the repeated measures design, and was fitted using maximum likelihood with Laplace approximation.

The model fit was assessed using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), with values of 839.1 and 866.4, respectively. Scaled residuals indicated a reasonable fit to the data, with a median of 0.456 and residuals ranging from -3.28 to 1.04.

Random Effects

The model incorporated random intercepts for subjects and blocks, with a variance of 0.574 (SD = 0.758) for subjects and a variance of 0.000 (SD = 0.000) for blocks, indicating that variability was primarily among subjects.

Fixed Effects

The fixed effects for distractor condition, anxiety, and their interaction are summarized in Table 9:

Table 9:

Mixed-Effects Model 1 Predicting Accuracy in the Child Sample

Predictor	**Estimate**	**Std. Error**	**z-value**	**p-value**
Intercept	0.795	0.223	3.565	<0.01**
Distractor Condition (No Distractor)	0.300	0.184	1.627	0.10
Anxiety	-0.003	0.228	-0.015	0.99
Distractor Condition × Anxiety Interaction	0.073	0.198	0.368	0.71

Summary of Findings

In this model, neither the distractor condition nor anxiety had significant effects on accuracy. The interaction between distractor condition and anxiety was also non-significant, suggesting that accuracy was not meaningfully influenced by the presence of distractors or participants' anxiety levels in this task. These findings indicate that distractors did not significantly affect accuracy in the child sample.

Model 2 (Child Sample):

Linear Mixed-Effects Model: Distractor Presence and Anxiety ~ Response Time

A linear mixed-effects model (LMM) was employed to investigate the effects of distractor condition, anxiety, and their interaction on response time. The model included random intercepts for subjects and blocks to accommodate the repeated measures design and was fitted using restricted maximum likelihood (REML).

The model fit was assessed using the REML criterion (1,627.8). Scaled residuals indicated a reasonable fit to the data, with a median of -0.200 and residuals ranging from -1.71 to 6.56.

Random Effects

The model incorporated random intercepts for subjects and blocks, with variances of 1.216 (SD = 1.103) for subjects and 0.036 (SD = 0.189) for blocks, indicating more variability between subjects than between blocks.

Fixed Effects

The fixed effects for distractor condition, anxiety, and their interaction are summarized in Table 10:

Table 10:

Mixed-Effects Model 2 Predicting Response Time in the Child Sample

Predictor	Estimate	Std. Error	t-value	p-value
Intercept	3.411	0.882	3.866	<.01

Predictor	Estimate	Std. Error	t-value	p-value
Distractor Condition (No Distractor)	-0.484	0.344	-1.406	0.16
Anxiety	-0.066	0.055	-1.202	0.23
Distractor Condition × Anxiety Interaction	0.011	0.021	0.514	0.61

Summary of Findings

In this model, neither the presence of distractors nor anxiety had significant effects on response time. The interaction between distractor condition and anxiety was also non-significant, indicating that response times were not meaningfully influenced by the presence of distractors or participants' anxiety levels. These findings suggest that, in this task, distractors did not adversely affect response time, regardless of individual differences in anxiety.

Model 3 (Child Sample):

Generalized Linear Mixed-Effects Model: Response Conflict and Anxiety ~ Accuracy

A generalized linear mixed-effects model (GLMM) was used to examine the effects of response conflict, anxiety, and their interaction on accuracy using a binomial distribution with a logit link function. Random intercepts were included for subjects to account for the repeated measures design, and the model was fitted using maximum likelihood estimation via the Laplace approximation.

The model fit was evaluated using the Akaike Information Criterion (AIC = 526.3) and the Bayesian Information Criterion (BIC = 550.8). Scaled residuals showed a reasonable fit, with a median of 0.36 and a range from -3.02 to 1.26.

Random Effects

Random intercepts for subjects were estimated with a variance of 0.811 (SD = 0.900), suggesting notable variability between subjects.

Fixed Effects

The fixed effects of response conflict, anxiety, block number, and their interaction are summarized in Table 11 below:

Table 11:

Mixed-Effects Model 3 Predicting Accuracy in the Child Sample

Predictor	Estimate	Odds Ratio	Std. Error	z-value	p-value
Intercept	0.642	1.9	0.417	1.539	0.12
Response Conflict	0.436	1.55	0.220	1.979	0.05*
Anxiety	-0.236	0.79	0.299	-0.789	0.43
Block Number	-0.012	0.99	0.153	-0.077	0.94
Response Conflict × Anxiety Interaction	0.491	1.63	0.239	2.055	0.04*

Summary of Findings

This analysis revealed that participants' accuracy was significantly influenced by the presence of response conflict. Participants performed more accurately in the non-conflict condition. However, anxiety alone did not have a significant effect on accuracy. Importantly, the significant interaction between response conflict and anxiety suggests that the relationship between response conflict and accuracy was moderated by participants' anxiety levels. Specifically, simple slope analysis revealed that for children scoring 1sd below the mean on anxiety, there was no significant difference in performance across response conflict ($\beta = -.05$, $z = -.016$, $p = .86$), whilst for children scoring 1sd above the mean, there was a significant decrease in performance in conflict conditions compared to non-conflict conditions ($\beta = .92$, $z = 2.85$, $p = <.01$). These findings highlight the complex interplay between response conflict and emotional factors in determining task performance.

Model 4 (Child Sample):

Linear Mixed-Effects Model: Response Conflict and Anxiety ~ Response Time

A linear mixed-effects model (LMM) was used to assess the effects of response conflict, anxiety, and their interaction on response time. The model included random intercepts for subjects and blocks, reflecting the repeated measures design, and was fitted using restricted maximum likelihood (REML).

The model fit was evaluated using the REML criterion (1,028.1). Scaled residuals showed reasonable distribution, with a median of -0.16 and residuals ranging from -2.02 to 6.05.

Random Effects

Random intercepts were included for subjects and blocks, showing variance of 1.89 (SD = 1.38) for subjects and 0.06 (SD = 0.25) for blocks. This indicates larger variability between subjects than blocks.

Fixed Effects

The fixed effects of response conflict, anxiety, and their interaction are summarized in Table 12 below:

Table 12:

Mixed-Effects Model 4 Predicting Response Time in the Child Sample

Predictor	Estimate	Std. Error	t-value	p-value
Intercept	3.244	1.138	2.851	<0.01**
Response Conflict	0.261	0.432	0.604	0.55
Anxiety	-0.039	0.073	-0.529	0.60
Response Conflict × Anxiety Interaction	-0.038	0.028	-1.366	0.17

Summary of findings

The effect of response conflict was not significant, suggesting no substantial difference in response time between conflict and non-conflict conditions.

Anxiety did not significantly affect response time.

The interaction between response conflict and anxiety was also non-significant, indicating that anxiety levels did not significantly modulate the effect of response conflict on response time.

Model 5 (Child Sample):

Generalized Linear Mixed Model: Perceived Threat and Anxiety ~ Accuracy

A generalized linear mixed model (GLMM) was performed to investigate the effects of perceived threat, anxiety, and their interaction on accuracy. The model employed a binomial distribution with a logit link function and included random intercepts for subjects and blocks to account for the repeated measures design.

The model fit was assessed using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), resulting in values of 574.7 and 599.6, respectively. The log-likelihood was -281.3, and the deviance was 562.7.

Random Effects

The model included random intercepts for subjects and blocks, with a variance of 0.705 (SD = 0.840) for subjects and 0.004 (SD = 0.063) for blocks, indicating more variability between subjects than between blocks.

Fixed Effects

The fixed effects for perceived threat, anxiety, and their interaction are summarized in Table 13:

Table 13:

Mixed-Effects Model 5 Predicting Accuracy in the Child Sample

Predictor	Estimate	Odds Ratio	Std. Error	z-value	p-value
Intercept	0.512	1.67	0.380	1.348	0.18
Perceived Threat	0.141	1.15	0.140	1.008	0.31
Anxiety	-0.161	0.85	0.407	-0.395	0.69
Perceived Threat × Anxiety Interaction	0.079	1.08	0.160	0.492	0.62

Summary of Findings

In this model, neither perceived threat nor anxiety had significant effects on accuracy, and the interaction between these variables was also non-significant. This suggests that accuracy was not meaningfully influenced by perceived threat or anxiety levels in this task.

Model 6 (Child Sample):

Linear Mixed-Effects Model: Perceived Threat and Anxiety ~ Response Time

A linear mixed-effects model (LMM) was conducted to examine the effects of perceived threat, anxiety, and their interaction on response time. The model included random intercepts for subjects and blocks, accounting for the repeated measures design, and was fitted using restricted maximum likelihood (REML).

The model fit was evaluated using the REML criterion, which was 1088.2. Scaled residuals indicated a reasonable fit to the data, with a median of -0.169 and residuals ranging from -2.31 to 6.64.

Random Effects

The model incorporated random intercepts for subjects and blocks, with a variance of 1.573 (SD = 1.254) for subjects and 0.068 (SD = 0.261) for blocks, indicating more variability between subjects than between blocks.

Fixed Effects

The fixed effects for perceived threat, anxiety, and their interaction are summarized in Table 14:

Table 14:
Mixed-Effects Model 6 Predicting Response Time in the Child Sample

Predictor	Estimate	Std. Error	t-value	p-value
Intercept	1.725	1.215	1.420	<.01**
Perceived Threat	0.851	0.334	2.547	.80
Anxiety	0.042	0.075	0.563	.27
Perceived Threat × Anxiety Interaction	-0.054	0.021	-2.591	.010*

Summary of Findings

In this model, perceived threat had a significant positive effect on response time, while anxiety alone did not significantly influence response time. Simple slope analysis revealed that response time increased as the perceived threat of distractors increased for children scoring 1 SD below the mean on anxiety ($\beta = 0.34$). In contrast, for children scoring 1 SD above the mean, response time decreased as perceived threat increased ($\beta = -0.26$). This indicates that children with higher levels of anxiety responded faster when distractors were perceived as more threatening.

Summary of Results (Child Sample)

The current study employed linear mixed-effects models and generalized linear mixed models to investigate the effects of perceived threat, anxiety, and distractor presence on response time and accuracy in a child sample. Whilst this is a small sample of only 15 participants, the findings indicate several key insights:

Response time:

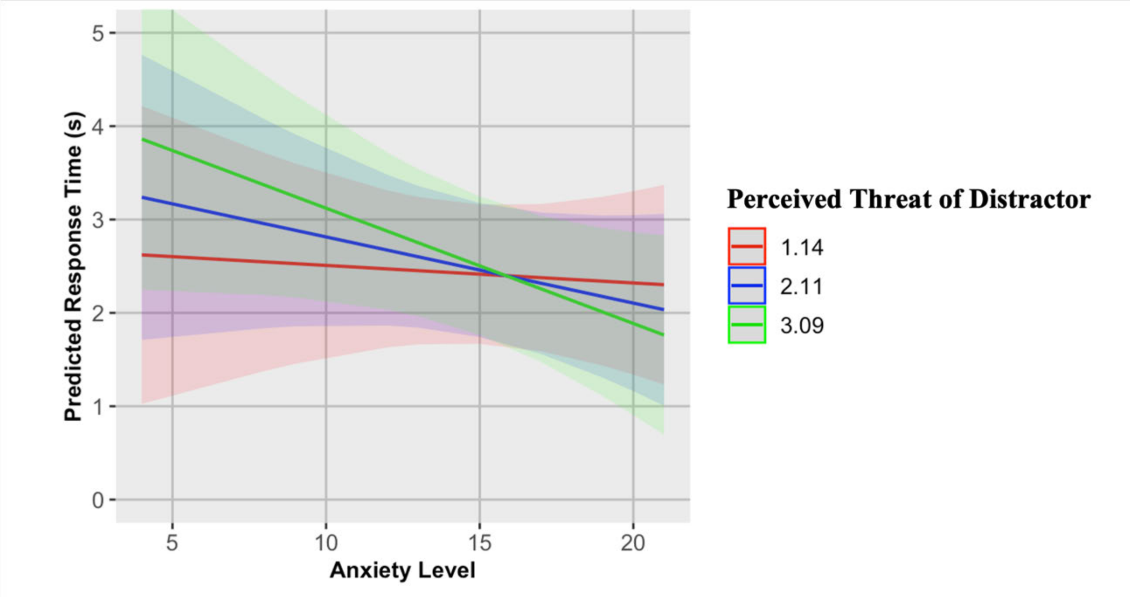
Differences in response time were significant only in Model 6, which showed a notable interaction between anxiety and perceived threat. Specifically, children with higher levels of anxiety exhibited a decrease in response time as the distractor stimuli were perceived as more threatening, whereas this pattern was reversed for children with lower levels of anxiety. Figure 42 graphically illustrates this interaction. This finding contrasts with **Hypothesis 4**, which proposed no interaction between perceived threat and anxiety on performance. Possible explanations for this unexpected interaction are explored in the discussion section.

Accuracy:

Contrary to **Hypothesis 1a**, we found no significant differences in response time or accuracy between trials with and without distractors. However, accuracy was significantly influenced by response conflict and the interaction between response conflict and anxiety, as illustrated in Figure 43. These findings support **Hypotheses 1b** and **2b**, showing that children performed better in non-conflict trials compared to conflict trials, and that this effect was moderated by anxiety. Specifically, children with higher anxiety exhibited impaired attentional control. This contrasts with findings from the adult study, where no interaction between response conflict and anxiety was observed. Interestingly, our alternative measure of attentional control—performance on distractor versus no-distractor trials—did not yield significant results, which contradicts **Hypothesis 2a**. Furthermore, neither perceived threat nor its interaction with anxiety impacted accuracy, challenging both **Hypothesis 3** and **Hypothesis 4**.

Figure 42:

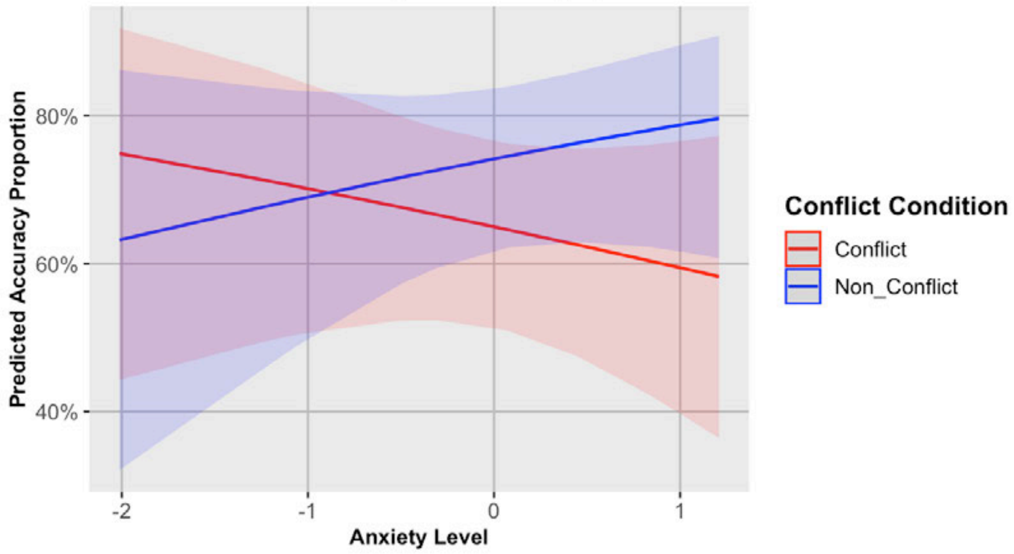
Interaction Effect of Perceived Threat and Anxiety on Response Time



Note: This interaction plot displays predicted response times as a function of perceived threat of distractors and anxiety level. Coloured lines represent different levels of perceived threat, calculated as the average post-test rating of the three distractor images for each trial. Red, blue, and green lines represent 1 SD above the mean, the mean, and 1 SD below the mean for threat ratings, respectively.

Figure 43:

Interaction Effect of Response Conflict and Anxiety on Accuracy Proportion



Note: This interaction plot displays the predicted accuracy proportions as a function of anxiety levels and trial conflict condition. The coloured lines represent different conflict conditions (red for conflict, blue for non-conflict), illustrating how the accuracy of responses varies with normalised anxiety levels.

Developmental Analysis

A further developmental analysis was run to explicitly examine how these differences in attentional control may express over the course of development. Data sets for adult and child samples were combined with respective anxiety measures normalised.

A generalized linear mixed model (GLMM) was conducted to examine the effects of block number, age, response conflict, anxiety, and their interactions on accuracy. The fixed effects included the main effects of response conflict, anxiety, and age, as well as their interactions, with a random intercept for subject number.

Results indicated a marginal interaction effect between response conflict, anxiety, and age, $b=0.128$, $SE=0.077$, $z=1.662$, $p=0.097$, suggesting that the relationship between response conflict and anxiety on accuracy might vary with age. Although this interaction was not statistically significant at the 0.05 level, the trend suggests that age may play a role in moderating the effect of conflict on anxiety-related performance, especially when considering the small sample size of only 15 child participants.

Chapter 8

Discussion

The current study aimed to explore the relationship between attentional control, attentional bias, and anxiety by employing a new behavioural paradigm designed to address limitations in the existing literature. Previous research on this relationship has often relied on self-report measures of attentional control, such as the Attentional Control Scale (ACS), which has been shown to have validity issues (Todd et al., 2022). To overcome these limitations, we implemented an adapted visual short-term memory (VSTM) task that enabled the concurrent measurement of attentional control and attentional bias by introducing distractor images with varying perceived threat levels.

Our study included two distinct samples: adults and children aged 5–14 years, the latter group representing a critical period for the development of attentional control. Studies on attentional biases and control in anxious adults have found that individuals with higher anxiety often show both reduced attentional control and a heightened bias toward threat (Bar-Haim et al., 2007; Eysenck et al., 2007). Consequently, we hypothesized that in our adult sample, individuals with higher anxiety would exhibit both impaired attentional control and an attentional bias toward threat. In contrast, we expected that in our child sample, only attentional control would be impaired for children with higher levels of anxiety, highlighting developmental differences and a distinct relationship between these constructs across age groups.

In the adult sample, our results demonstrated the sensitivity of the task to attentional control abilities, as both the presence of distractors and response conflict significantly impacted accuracy. In the child sample, whilst underpowered, we observed a significant effect of response conflict, indicating that children engaged attentional control processes to manage the competing outcomes of distractors and target stimuli. Interestingly, attentional control was not influenced by anxiety in adults, whereas in children, higher levels of anxiety were associated with reduced attentional control. Moreover, adults with higher anxiety levels demonstrated improved performance as the perceived threat of distractor stimuli increased. In contrast, among children, neither perceived threat nor its interaction with anxiety had a notable impact on accuracy.

Previous literature suggests that all children initially display an attentional bias toward threat. As they develop, some children learn to inhibit this bias, potentially through the recruitment of prefrontal control mechanisms involved in attentional control—a process described by the *Moderation Model* (Field & Lester, 2010). In this model, attentional control acts as a moderator, allowing certain individuals to reduce their attentional bias to threat over time. Other children, however, may continue to exhibit this bias into adulthood, potentially contributing to heightened anxiety levels. Previous findings support this account, showing that attentional bias toward threat in adults is moderated by attentional control (Shi et al., 2019), although much of this research has relied on self-reported attentional control measures.

Adult Sample

Previous research suggests that adults with higher anxiety often display reduced attentional control compared to those with lower anxiety (Eysenck et al., 2007). However, contrary to this literature, we found no significant interaction between anxiety and either distractor presence or response conflict in our study. This suggests that individuals with higher levels of anxiety did not experience greater difficulty in filtering out distractors or managing competing outcomes compared to individuals with lower anxiety. These findings question the assumption that attentional control is universally impaired in individuals with higher anxiety, as suggested by the Attentional Control Theory (ACT).

This discrepancy may be explained by recent criticisms of self-report attentional control measures. Studies have raised concerns that self-reported attentional control scores may reflect individuals' beliefs about their attentional abilities rather than their actual capabilities (Todd et al., 2022). The over-reliance on these measures in the literature may exaggerate the differences between people with higher and lower anxiety. People with higher anxiety might have intact attentional control but may perceive their abilities as lower due to challenges with self-monitoring or self-belief.

Interestingly, we observed an interaction between threat level and anxiety on performance, although the effect was opposite to our predictions: individuals with higher anxiety performed better with distractor images that they rated as more threatening. If participants with higher anxiety had shown an attentional bias toward threat, we would have expected a decline in performance or an increase in response times—neither of which we observed. Similar patterns have been observed in previous studies on attentional bias in anxiety, but only with display times longer than 1000 ms, where individuals with higher anxiety tend to avoid threatening stimuli (see Bar-Haim et al., 2007, for a review). Our display time of 300 ms was specifically chosen to capture an attentional bias toward threat, yet our results instead point to an attentional avoidance.

Our findings, namely the absence of deficits in attentional control among anxious individuals and their improved performance in the presence of perceived threat, suggest that anxiety may not necessarily impair attentional control. Rather, individuals with higher anxiety may exhibit an enhanced ability to avoid threatening stimuli, potentially as an adaptive coping mechanism in response to the heightened salience of these stimuli. Supporting this view, Bishop (2009) found that under high cognitive load, no significant differences emerged in attentional abilities between high- and low-anxiety individuals. Performance differences only appeared under low perceptual load, where low load allowed salient distractors to compete for attention, whereas high load limited attentional resources available for distraction.

While Bishop's interpretation attributes these differences to variations in attentional capacity, our findings suggest an alternative explanation for previous results: individuals with higher anxiety may prioritize avoiding threatening stimuli over task performance, especially in low-load conditions where this trade-off is more achievable. Rather than an attentional control deficit, a focus on attentional avoidance could account for the observed differences in task goals between high- and low-anxiety individuals, particularly when cognitive demands are low.

Evidence shows that individuals with higher anxiety maintain intact prefrontal control abilities, as demonstrated by their comparable performance with non-anxious individuals on high-load tasks. However, a goal-oriented drive to avoid threatening stimuli becomes apparent when anxious individuals have spare attentional resources. In these situations, they seem to juggle the conflicting goals of task success and threat avoidance, potentially compromising task performance when the task is easy enough to allow this balancing act.

Under higher cognitive loads, individuals with higher anxiety may prioritize task performance over threat avoidance, as the demand of the task itself leaves fewer resources for avoidance behaviours. Although more evidence is needed to fully support this hypothesis, our task setup provides a strong foundation for testing these claims, as it allows for easy manipulation of cognitive load by either increasing the number of stimuli to be encoded or decreasing display times.

Alternatively, it is possible that the threat level of even the high-threat images in this lab setting was insufficient to disrupt attentional control, though it may have been sufficient to enhance motivation. The ability to manipulate the threat level of images is a key strength of this task and could be leveraged to test this alternative explanation.

Child Sample

Meta-analytic evidence suggests that attentional control abilities improve across development, with younger children generally exhibiting deficiencies in attentional control. As children mature, those with lower anxiety tend to develop intact attentional control abilities, while those with higher anxiety may continue to display deficits (Dudeney et al., 2015). Our findings align with the meta-analysis by Dudeney et al. (2015), which indicates that attentional bias toward threat is present across young children but becomes moderated by anxiety as they approach middle childhood. According to Dudeney et al., younger children show a generalized bias toward threat, regardless of anxiety levels. As they reach middle childhood, differences begin to emerge between high- and low-anxiety individuals. Our findings also support the Moderation Model, which posits that deficiencies in attentional control contribute to the emergence and maintenance of attentional biases toward threat, potentially leading to the development or maintenance of anxiety.

Research on attentional biases toward threat in children, however, has been mixed. Some studies support the presence of a threat bias in children (Kindt et al., 1997a; Kindt et al., 1997b), while others do not (Martin et al., 1992). In our study, we observed results that align more closely with developmental theories of anxiety. Specifically, we found an interaction between anxiety and response conflict on performance, indicating that children with higher anxiety levels exhibit poorer attentional control. However, we did not observe an interaction between anxiety and perceived threat, suggesting an absence of an attentional bias toward threat in children.

However, it is important to interpret these findings cautiously due to the limited sample size in our study.

Developmental Trends

The developmental trajectory of attentional control as predicted by the Moderation Model was assessed through assessment of attentional control in adults and children across different levels of anxiety. Although the child sample was small, our results indicated a trend suggesting that the difference in attentional control between individuals with high or low anxiety is more pronounced in children than in adults. Specifically, anxious children showed a larger performance decrement in response conflict conditions compared to non-anxious children, with this difference diminishing with age. These findings suggest that while attentional control varies significantly with anxiety levels in childhood, these differences tend to decrease over time, and by adulthood, most individuals develop stable attentional control abilities.

Interestingly, our results suggest a potentially opposite pattern for attentional bias, where differences in attention toward threat between anxious and non-anxious individuals was significant in adults but not in children. One possible explanation for this pattern is that anxious children may experience a delayed development of attentional control. This delayed development may contribute to a growing attentional bias toward threat over time. Children with higher anxiety exhibit a diminished capacity for attentional control, which amplifies their attention towards threatening stimuli and drives a goal-directed prioritization of threat-related information. Although they eventually develop attentional control as they age, this attentional bias toward threat may persist due to top-down differences in the allocation of attention to threat.

Further research should focus on this critical developmental period, as a larger sample would allow for a more detailed analysis of how attentional control and attentional bias develop and interact across age and anxiety levels. Such work could provide valuable insights into how these constructs evolve and influence each other over time.

It is important to consider the limitations of developmental comparisons in this study due to the slight differences in task design for the adult and child samples. Specifically, the display time was extended for the child sample to make the task "easier" and ensure roughly comparable performance levels between adults and children. This approach enabled a good range of performance across age groups but introduced potential limitations in interpreting differences between the adult and child samples. A key benefit of this methodology, however, is the flexibility to adjust task parameters, allowing for easy manipulation of cognitive load. Future research could leverage this design characteristic to address the limitation by administering both a low cognitive load (“easy”) and a high cognitive load (“hard”) version of the task to adults and children. This would allow for statistical control of task difficulty in analyses, providing more robust developmental comparisons.

Future Directions and Limitations

While the present study offers insights into potential gaps in the literature regarding the role of attentional control in anxiety across development, these findings are preliminary due to the small child sample of only 15 participants. A properly powered study with a broader distribution of participants across age groups would allow for a more accurate and reliable understanding of how attentional control and attentional bias evolve over development. Longitudinal data is also needed to explore the causal links proposed by the moderation model and other theories regarding the role of attentional control in the development of anxiety and attentional biases.

Additionally, this study did not observe significant differences in the threat levels of the images used, highlighting a potential limitation in the effectiveness of these stimuli. Future research should consider using images with potentially higher valence to better capture the intended emotional responses. The lack of significant differences between these images, selected from the widely used IAPS database, raises questions about the emotional impact that these images actually evoke. This finding serves as a caution for researchers relying on the IAPS, suggesting that these images may not consistently produce the effects assumed. Future studies should further investigate this issue, as a substantial body of research has utilized the IAPS, and its limitations in evoking targeted emotions could affect findings across numerous studies.

Future research should further examine the limitations of self-reported attentional control measures. The relationship between perceived attentional control and anxiety remains of interest, particularly in terms of how this perception interacts with behaviourally measured attentional control and attentional bias across development. Adults with higher anxiety may not exhibit behavioural deficits in attentional control, yet they consistently rate their own attentional control abilities lower than individuals with lower anxiety (Shi et al., 2019). This discrepancy in cognitive self-monitoring may result from a bias toward negative prediction errors (PEs), a cognitive process linked to anxiety development.

Individuals constantly make predictions about the outcomes of their actions and the events around them. When these predictions do not align with actual outcomes, a prediction error occurs, driving learning and shaping future behaviour. Positive PEs occur when outcomes are unexpectedly favourable, while negative PEs occur with unfavourable surprises. Some researchers suggest that a bias toward negative PEs could lead to an overemphasis on these instances, prioritizing their avoidance in future situations, potentially fostering anxiety (Villano et al., 2023). This negative PE learning bias may explain the self-perceived attentional control deficit seen in individuals with higher anxiety. These individuals may be overly critical of their attentional control abilities, focusing disproportionately on past failures. Future studies should target the role of negative PEs in shaping self-reported attentional control, examining how these relate to behavioural measures of attentional control and attentional bias, which could clarify connections between attentional control perceptions, prediction error biases, and anxiety.

The lack of significant differences in response times across conditions may stem from the task design. While including distractor items in the test phase is crucial for assessing attentional control through response conflict, this setup might have affected response patterns based on anxiety levels. Highly anxious individuals may have responded faster to avoid engaging with threatening distractor items, potentially minimizing predicted differences in response times due to task efficiency. However, the increased accuracy among individuals with higher anxiety levels in threat conditions suggests that they actually found it easier to avoid these stimuli, rather than being more distracted by them.

Future studies could explore modifying the paradigm by removing distractors from the test phase, which would eliminate this possible confound. However, this adjustment would also prevent assessment of response conflict, which is another critical measure of attentional control.

Conclusion

In this study, we introduce a novel methodology for concurrently measuring attentional control and attentional bias through behavioural observation. Our adapted Visual Short-Term Memory (VSTM) task addresses two major limitations in the field: (a) the challenge of behaviourally measuring attentional control and attentional bias, and (b) the need for sensitivity to developmental differences. Using this task, we observed no overall deficits in attentional control across anxiety levels, contrasting with previous literature. However, we identified attentional control differences across anxiety levels specifically in children aged 7–12, highlighting the developmental significance of this construct within this age range.

Our findings suggest that individuals with higher anxiety may exhibit attentional biases toward threatening material due to systematic differences in performance goals rather than deficiencies in attentional control abilities, as has been commonly posited. Future research applying this paradigm within the critical 7–12 age group may reveal essential insights into the developmental trajectory and interrelation of attentional control and attentional bias.

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