Impacts of trait anxiety on attention and feature binding in visual working memory

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Doctor of Philosophy

August 2021

Author's Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date: 09/08/2021

List of Contents

List of Tables

List of Figures

List of Appendices

Acknowledgements

I would firstly like to thank Dr Louise Nicholls, who was the lead supervisor on this PhD. Louise has been my research supervisor ever since we started studying the effects of anxiety on working memory together back in 2014, during my Honours dissertation project. She has been an incredible supervisor and mentor, one who I have learned a lot from and who has had a tremendous influence on my professional development. Any successes that have led to the submission of this thesis are owed to her ongoing support over the years. I am grateful for the many opportunities she has afforded me to develop knowledge, confidence, and experience within psychological research. I am also grateful to Dr Marc Obonsawin for his thoughtful and insightful contributions to this thesis as second supervisor. Throughout this project Marc's guidance has helped me to better understand the importance of taking a considered approach to research design and analysis, and of taking the time to speak and write with greater clarity.

Thank you also to Dr Stephen Butler, who kindly served as annual reviewer for the progress of this PhD research, and whose interest in the work served as encouragement to push on at those critical points. I would also like to thank Dr Richard Allen and Dr Steve Kelly for agreeing to examine this thesis.

I'm indebted to all of those family, friends, friends of friends and fellow PhD students without whom recruitment for this research would probably still be ongoing. I thank all of them for the time that they dedicated over the past several years as study pilots and participants, and for their resourcefulness in helping to recruit for these studies. In particular I'd like to underline my gratitude to my family who have been unconditionally supportive during my time in undergraduate and postgraduate study.

As with my supervision team, it is their support that has made studying towards this PhD and completing this thesis not only possible, but also such an enjoyable experience.

Finally I am grateful to all of the individuals who took part in this research, as well as those who collaborated on each project – particularly the two groups of Honours students who contributed to data collection for the final two studies reported here – for their fundamental contribution to the formation of this thesis. Thank you also to the University of Strathclyde for funding this PhD and the staff within Strathclyde Psychology, who it has been a pleasure to learn from and work with over the best part of the last decade.

Abstract

In their Attentional Control Theory (ACT), Eysenck et al. (2007) suggested that anxiety impacts top-down and bottom-up attentional processes. Elsewhere, Hitch et al. (2020) have posited that both top-down and bottom-up attention are key components of visual working memory. Although there is some existing evidence that trait anxiety disrupts visual working memory (e.g., Moreno et al., 2015; Spalding et al., 2021), investigations of the relationships amongst anxiety, attention, and working memory remain limited. Further research is needed to determine the degree to which experiences of anxiety are related to attention, and how these experiences could affect working memory. The aim of this research was to determine attentional factors that influence feature binding in visual working memory, and how these may interact with self-reported trait anxiety. Studies 1 and 2 respectively assessed the role of cognitive strategies (prioritisation) and suffix presentation (interference) in memory performance. In each case, there were no significant effects of anxiety observed. Accounting for potential individual differences in working memory capacity, which may be affected by anxiety, Studies 3 and 4 assessed whether cognitive load (low vs high), memory type (shape vs binding), or memory set size (three vs four items) affected performance and interacted with anxiety. Results supported previous research (Spalding et al., 2021), whereby moderate-to-high levels of self-reported trait somatic anxiety were associated with reduced binding memory. Moreover, trait cognitive anxiety was associated with improved individual feature memory. Findings suggest that higher levels of anxiety may be associated with enhanced visual perception, but also reduced working memory capacity. This supports the assumption in ACT that anxiety diminishes cognitive performance by occupying executive resources and

facilitating perceptual processing. Future research should aim to develop on the novel findings of this work to better determine the specific experiences of anxiety that may impact cognitive performance.

1 Visual working memory and attention

1.1 Chapter overview

This thesis documents a series of experimental investigations into the effects of anxiety on visual working memory, the system responsible for the processing and temporary storage of visual material. Anxiety, an emotional experience characterised by worry and fear regarding potential threat or negative outcomes, impacts top-down and bottom-up attentional processes. Recent studies in the visual working memory literature implicate both top-down and bottom-up attention in working memory processing. Given the effects of anxiety on attention, and the role of attention in visual working memory, it is likely that anxiety affects visual working memory. It is likely that this occurs specifically either through top-down or bottom-up attentional processes, or both. However, investigations of impacts of anxiety on visual working memory remain limited. Further research is needed to determine the degree to which specific experiences of anxiety are related to attention, and how these may in turn affect the manipulation and maintenance of information in working memory. This is particularly true for visual working memory, as contemporary studies in this area represent the state-of-the-art in terms of paradigms that can help to develop understanding of the relationship between attention and working memory. This chapter details the development of the visual working memory literature base. In the first instance, an overview of the memory system will provide context for the central role of working memory in everyday cognition. The structure and functioning of working memory will then be discussed, highlighting the value of working memory models in explaining a diverse range of empirical findings. The chapter will finally focus on the developing understanding of visual working memory, which directly informs the empirical investigations reported in Chapters 4-7 of this thesis. This chapter will also introduce the context for the discussion of the relationship between anxiety, attention and working memory, which is given focus in Chapter 2.

1.2 Memory and cognition

The term *cognition* broadly encompasses processes such as perception, attention, and memory across sensory domains (e.g. visual or auditory) and action outcomes. Neisser (1967) summarised cognition as the processes used to interpret and mentally manipulate stimuli, citing examples such as imagery, problem-solving and recall. From the cognitive perspective, human thought and action is a systematic process. Sensory information must be processed and modulated along a stream of neural systems in order to be integrated into cognition, beginning at initial perception (Mesulam, 1998). Consider the processes involved in visual cognition, for example. Light energy is projected onto the retina and converted into a neuronal signal, which is transferred via the optic nerve to the primary visual cortex, located in the occipital lobe of the brain (Breedlove & Watson, 2013). This is then processed via a ventral stream, responsible for object detail information (the 'what' pathway), and dorsal stream, responsible for spatial information, as well as ego-centric, visually-guided action and navigation information (the 'where' and 'how' pathways; e.g. Creem & Proffitt, 2001; Kravitz et al., 2011). Within this framework, cognition can also be seen to involve top-down processes, responsible for the active engagement with stimuli following initial registration in order to arrive at useable visual representations (Cavanagh, 2011).

Crucially, the term *cognition* encompasses the top-down manipulation of bottom-up cortical signals, suggesting that a unidirectional account of processing – i.e., starting at sensory input - is not sufficient to explain human thought and action. That is, cognition is an interaction between each set of processes (Gilbert & Sigman, 2007), wherein the physiological streams themselves are bidirectional (Mesulam, 1998).

Cognitive processing from bottom-up, initial perception to top-down control can be succinctly illustrated via the modal memory model (e.g. Atkinson & Shiffrin, 1968; see Figure 1.1). The memory system, at the highest level, was considered to consist of a permanent underlying structure of fixed processes, as well as control processes that are utilised at the volition of the individual. These control processes were argued to be variable depending on the specificity of a given situation. Employing a mind-computer analogy, the structural processes can be likened to fixed hardware and programming reserved for operation and storage. The control processes then reflect the instructions entered into the computer by its operator to execute specific outcomes. Structurally, the memory system can be broadly separated into three components, initial sensory registers, a short-term store and a long-term store. This basic framework remains relevant in illustrating the common theoretical features of memory (Eysenck & Keane, 2010), with researchers typically assuming the existence of these three basic forms of storage (Baddeley et al., 2015). It provides a means of describing the processes by which external information is initially perceived, before being utilised/maintained in short-term storage and potentially committed to/retrieved from long-term storage.

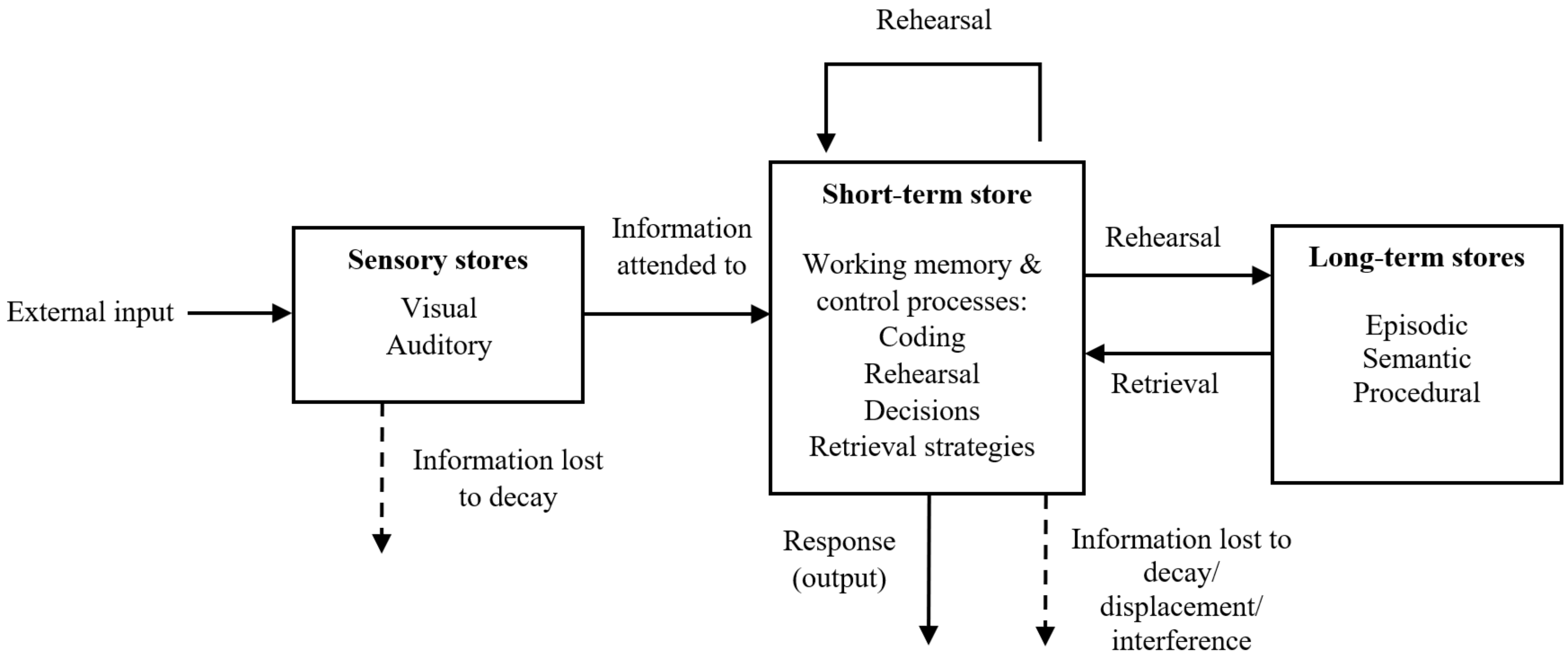

Figure 1.1 The modal memory model, illustrating the main stages of memory and features of each (adapted from Baddeley, 1999).

The development of the understanding of sensory, short-term and long-term memory is detailed in the following subsections. The intention in these sections is to highlight the key phenomena associated with each type of memory and highlight the different role of each in broader cognition. Rather than the model being presented as the definitive structural representation of memory, it will be described in order to provide context for the discussion of working memory beginning in Section 1.3. This approach has been taken due to the fact that working memory, as it is commonly understood in contemporary research, may be viewed as an elaboration on the short-term store of the modal model, and the broader modal model remains useful as a general framework for interpreting current findings (Baddeley et al., 2019).

1.2.1 Sensory memory

Sensory information is thought to be registered immediately, but with rapid decay (e.g. 100 ms for visual information; Philips, 1974). Sensory registration represents the first stage of cognitive processing that occurs after encountering external stimuli. Following Neisser’s (1967) coining of separable iconic and echoic memory stores (i.e. the brief memory for visual sensation and auditory sensation, respectively), Atkinson and Shiffrin’s (1968) modal model made initial steps towards separating memory components. This was according to sensory modality, suggesting the existence of visual sensory and a-v-l (audio-verbal-linguistic) stores. Although it has been assumed that similar storage systems also exist for other senses (e.g. haptic/olfactory/gustatory), these have received limited theoretical and empirical attention in comparison to the visual and verbal domains (Baddeley, 2012).

Evidence for sensory memory originally developed from studies of visual imagery. Partial vs full report studies (e.g. Sperling, 1960) provided the primary evidence for the phenomenon. In these tasks, participants were presented with to-be-remembered items very briefly (e.g. 50 ms). They were able to remember a greater proportion of items when they were cued to recall a specific subset, rather than the whole array. However, this effect reduced as the delay between the memory array presentation and cue increased (up to, for example, 300 ms). Therefore, despite the visual array disappearing, a sensory trace remained in memory that allowed for focusing upon and recalling a relatively consistent quantity of information, providing that memory was probed at a sufficiently short duration after presentation. The superiority of partial vs full report has also been observed when the instruction is based on various object features other than their location, such as size and colour (von Wright, 1968) as well as shape (Turvey & Kravetz, 1970). Partial report was also shown to be superior to full report in the a-v-l domain, although the effect reduced over a longer period of time than in the visual domain (~ 4000 ms; Darwin et al., 1972). The concept of a sensory register was therefore based on evidence that a large quantity of information could be accessed in the immediate aftermath of exposure to stimuli, but only within a period of several hundred milliseconds for visual information and up to four seconds for auditory information.

1.2.2 From sensory to short-term memory – the role of attention

The concept of a sensory register provides a means of explaining how external information is initially perceived and processed after being encountered. However it does not account for how information is selected and reinforced in order to influence thought and action, and to form long-term memories. In the modal model, short-term memory represents the next stage in processing after sensory memory. Despite still being limited in temporal capacity, the short-term store is representative of the means by which the individual exercises the various control components that are responsible for how information progresses through the memory system as a whole.

Attention would appear to have both early- and late-stage roles for information selection in memory. The early-stage role was demonstrated in dichotic listening studies (e.g. Treisman & Geffen, 1967; Treisman & Riley, 1969). Here, participants were instructed to repeat, or 'shadow', a single message played in one ear but indicate the presence of the same target word in messages played simultaneously in each ear. It was found that participants were more likely to identify the target in the shadowed message. Thus, it appeared that task responses were dependent on initial attendance to stimuli, rather than selection of all presented perceptual information.

The current understanding of attention in working memory, incorporating later attentional processing, can be seen to stem from evidence that attention exists firstly as automatic perceptual activation, but also as controlled, consciously guided attention (e.g. Shiffrin & Schneider, 1977). Treisman and Gelade's (1980) theory of selective attention further formalized these findings, providing an account that embeds attentional processes within working memory. Here, it is suggested that object features are automatically detected and analysed at a pre-attentive stage, before being combined and registered as complete objects under conscious, focused attention (see Sections 1.3.5 and 1.4.1).

There is good reason to have referred briefly to this early work in describing the broader memory system. Early assumptions surrounding the application of attention to memoranda broadly concurred on key outcomes. In the first instance, a core assumption underlying these theories was a functional role of attention in memory, to which it contributes the selection of perceived information for short-term processing. Specifically, attending to certain information was thought to prioritise it for further processing, compared with competing, unattended information. Secondly, and of particular importance to the structure of the memory system, this early research indicated that there is a clear distinction between higher-capacity memory based on sensory information, and a limited-capacity memory responsible for subsequent processing, i.e. short-term memory.

1.2.3 Short-term memory

Restrictions in the capacity of short-term memory differ from those in sensory memory. In sensory memory, capacity restrictions reflect the rapid decay of information. Phillips (1974) provided evidence for the distinction between visual sensory and short-term storage. Participants could generally detect or reject changes in 8 x 8 visual matrices as well as 4 x 4 matrices with an inter-stimulus interval of 200 ms, but performance for the 8 x 8 matrices fell significantly at intervals of 1000 or 3000 ms. Despite this, memory for 4 x 4 matrices was similar across time points at intervals lasting up to 9000 ms. Thus, sensory storage appeared to be high in capacity, but very short duration (i.e. over periods of less than a second). By comparison, smaller quantities of information could be maintained and used to make accurate task responses over a longer, though still limited, time period.

These findings are illustrative of the capacity bottleneck of short-term memory, where fewer items are held for direct access than what was initially perceived and what can subsequently be recalled (Cowan, 2010). Henderson (1972) cited results from studies of location reports in visual matrices, digit and letter recall, and letter similarity judgements as converging on a short-term memory limit of four items plus-or-minus-one (see also Cowan, 2010).

It is however important to note that the capacity limits of short-term memory are flexible, an observation which has been apparent since seminal studies of short-term memory. Total memory object limits may vary according to opportunities to enact information processing strategies, deleterious effects of stimulus interference (e.g., from irrelevant or additional stimuli), or the decay of information over time. Early studies demonstrated a basic decay effect in short-term memory which occurs over a longer duration than that found in sensory memory. In the Brown-Peterson paradigm, participants were asked to encode, maintain, and then recall consonant trigrams (e.g., DMS) over a period of several seconds. Brown (1958; cited in Ricker et al., 2016) demonstrated that recall of information would decrease with the inclusion of a 5 s interval between stimulus presentation and test. Peterson and Peterson (1959) then demonstrated that recall would further decline as intervals increased (from around 80% accuracy for intervals of 3 s to 10% accuracy for intervals of 18 s). Importantly, these results varied according to participants' ability to verbally rehearse information. In the case of Brown's findings, performance dropped specifically when participants had to repeat digits during the delay phase, preventing stimulus rehearsal. Peterson and Peterson's results were obtained in conditions where participants were tasked with counting backwards during the interval phase. As such, decay was not strictly dependent on time. In a further test of stimulus decay from memory, Waugh and Norman (1965) found that forgetting occurred to a greater extent as a function of the number of items that had been presented following a target, rather than the rate at which information was presented. Therefore, reductions in recall ability could be seen to result from retroactive interference (i.e., more recently encountered stimuli interfering with memory for previously encountered stimuli), rather than pure temporal decay in the absence of rehearsal.

Later evidence from studies of visual memory illustrates the interplay between the effects described above. Phillips and Christie (1977; see also Phillips & Baddeley, 1971) found that visual patterns presented at the end of a sequence of to-be-remembered patterns were faster and more accurately recognised than those that came before, with the memory trace lasting approximately 10 s following an interval in which no further processing was required. However, with an interval involving an additional arithmetic task, this was reduced to 3 s. Effects of interval length, presentations rate, and the intervening task were not observed for earlier items. As such, a distinction can be observed between memory for recently encountered and previously encountered stimuli. The most recently presented information is easier to recall but more susceptible to interference (see also reference to the serial position effect in Section 1.2.4 and discussion of sequential binding studies in Section 1.4.1). Proactive interference (PI) effects have also been observed, whereby minimal forgetting occurs for a first to-be-remembered sequence of items, regardless of delay interval, but a greater degree of forgetting occurs for subsequent sequences (Keppel and Underwood, 1962). However, this would not occur when the type of memory stimuli was changed from what was initially presented (e.g. from letters to numbers), known as 'release from PI' (Wickens, 1970; Wickens et al. 1963). It is worth noting, however, that data from the same Brown-Peterson paradigm consisting of a single trial (i.e. tasks in which PI from previous trials was not possible) indicated decay effects at periods of up to 5 s (Baddeley & Scott, 1971). This suggests that the specific nature of the task may result in a different source of forgetting.

Thus, short-term memory was generally observed to be dependent on overall capacity limits and delay period, as well as being susceptible to interference. The retention of information in short-term memory in the face of these limitations appeared to be particularly dependent on the ability to rehearse the information. Alongside the effect of rehearsal observed by Brown (1958; cited in Ricker et al., 2016), further evidence would support that short-term memory maintenance and transfer of information to long-term memory relied on rehearsal.

1.2.4 From short-term to long-term memory

As will be discussed in greater detail from Section 1.3 onward, short-term memory has consistently been attributed an important functional role in the memory system, allowing sensory information to be consolidated and committed to long-term memory. However, it is useful to highlight the way in which working memory was initially conceptualized in the context of the modal memory model. The concept of short-term memory as a 'working' memory was introduced by Atkinson and Shiffrin (1971), who proposed that the short-term store served as a control system. This system was argued to be responsible for the processes by which new (i.e. sensory) information was acquired and old information (i.e. long-term memory traces) was retrieved in order to facilitate ongoing tasks. This view can be seen to extend from 'late-selection' models of attention (Deutsch & Deutsch, 1963, Norman, 1968; see also Atkinson & Shiffrin, 1968), wherein the selection of stimuli for semantic coding occurred at the short-term memory stage, rather than between perception and short-term memory.

An important function of short-term memory, as described by Atkinson and Shiffrin (1968), was the role of rehearsal in the short-term store in transferring information to a more permanent, potentially unlimited capacity, long-term memory. Based on evidence from free recall performance, they suggested that around four items can be rehearsed and thus maintained in short-term storage, in line with the capacity limits briefly highlighted above in Section 1.2.3. Longer rehearsal of items coincides with elaborative semantic coding of information and transferral to the long-term store. Craik and Lockhart (1972) provided a similar account of different ways in which stimuli are processed. They suggested shallow processing, that is the processing of auditory and visual material based on their physical characteristics, and deep processing, in which elaboration on rehearsed material (e.g. forming associations between materials) strengthens the memory trace. Indeed, evidence suggests that the nature of memory demonstrably changes when considering storage over the long term, supporting the view that there are separable short and long-term stores in memory.

Early experimental evidence highlighted the key phenomena that helped to parse the nature of short and long-term memory storage. Murdock (1962) found evidence for primacy and recency effects in recall wherein words presented at the beginning or end of a sequence were better remembered than those that came between (i.e. the 'serial position effect'). Subsequent studies demonstrated that recency effects were reduced by interference from a subsequently performed task (Glanzer & Cunitz, 1966), while primacy effects were boosted by increased presentations times (Glanzer, 1972). Therefore the earliest information encountered in a sequence could be rehearsed over a longer period and committed to long-term memory, while the latest information remained in short-term memory, having received insufficient rehearsal for long-term storage. Memory for mid-sequence items suffered to the greatest extent, being displaced by subsequent information but not encountered for sufficient duration to be transferred to long-term memory. Long-term storage was found not to be susceptible to short-term interference, and information was committed to long-term memory primarily through rehearsal.

1.2.5 Long-term memory

Where sensory memory reflects memory over a period of milliseconds, and short-term memory reflects storage over a period of – typically – a few seconds, long-term memory encompasses the storage of information over, potentially, a lifetime.

Baddeley (1966b) demonstrated that verbal memory is differentially impaired depending on whether it is held in short or long-term storage, and that long-term memory can be influenced by content stored in the short term. Previous studies demonstrated that lists of similar words are harder to recall accurately in the short term when they are acoustically, but not semantically, similar (Baddeley, 1966a; Conrad & Hull, 1964). Baddeley (1966b) extended this finding to memory for acoustically or semantically similar and dissimilar word lists using a surprise retest phase 20 minutes after short-term memory testing. Here, semantic similarity reduced recall at retest, but acoustic similarity did not. This occurred specifically when participants completed an interference task after the initial encoding phase, which further limited short-term verbal rehearsal. As such, coding in long-term memory was thought to be dependent on semantics (meaning) in the absence of short-term memory support, but also amenable to verbal coding when short-term memory resources were available to process and maintain information over time.

Baddeley's (1966b) study is particularly useful for illustrating the distinctions in short-term and long-term storage processes, but also that stimuli characteristics reflect how well they may be remembered. Tulving (1972) elaborated further on long-term memory characteristics, delineating episodic and semantic categories of memory. Episodic memory can be described as autobiographical memory of episodes/events that have or will happen. Semantic memory is generalised knowledge, independent of time (i.e., facts, such as names and places; Squire & Zola, 1996). While these types of memory represent explicit, 'declarative' recall of information, a third type of long-term memory - procedural memory - was suggested to represent 'non-declarative', implicit knowledge. This relates to the execution of learned actions and task performances without the need for conscious representation. This distinction is supported in the structural differences established between explicit and implicit memories in the brain. Studies of patients with amnesia have provided extensive evidence for separable memory systems. A medial temporal lobe memory system based primarily around the hippocampus and its associated cortices, is crucial in the formation of declarative memory (Squire & Zola-Morgan, 1991). The hippocampus appears to be responsible for the integration of sensory information from these adjacent brain areas into fragile, bound representations or associations which become reinforced over time as a cohesive memory after learning (Mesulam, 1998; Squire, 1992). Non-declarative memory, by comparison, encompasses various separate subtypes of memory across systems. Skills and habits are thought to be dependent on the striatum, priming and perceptual learning on the neocortex, motor responses on the cerebellum, and non-associative learning on neural pathways involved in reflexive responses (Squire, 2004). Emotional memory responses, i.e. the unconsciously learned emotional significance of events, is meanwhile thought to be largely dependent on the amygdala and its connected cortical areas (LeDoux, 2000). The exploration of the effects of emotional disposition on memory forms the basis for the experimental investigations detailed in Chapters 4-7 of this thesis, which are given detailed theoretical context in Chapter 2.

1.2.6 Summary of the modal memory model

There exists a wealth of evidence supporting the separation of memory into sensory, short-term, and long-term stores, at least as a means of explaining specific cognitive phenomena. The above discussion provides a concise overview of the development of our broad understanding of these systems. Sensory memory is suggested to be high in capacity, but to decay rapidly over time. In the relatively linear system proposed by the modal model, sensory memory represents the first stage of processing of external stimuli. Short-term memory represents a limited capacity system crucial for cognitive functioning, the content of which is dependent on attentional selection following initial sensory registration. The short-term memory system is responsible for how sensory information is consolidated, used for ongoing tasks, and potentially transferred to long-term memory for future recall. The system is also responsible for retrieving long-term memories. Capacity limits reflect the amount of information that can be processed simultaneously, which varies depending on whether information decays or is displaced. This information loss can potentially be offset by maintenance rehearsal. Information is stored in long-term memory as declarative episodic or semantic memory, or a variety of non-declarative memory types. Despite the value of the modal model in illustrating the broader memory system, contemporary research has further developed understanding of various specific aspects of this framework, including short-term memory.

1.3 Baddeley & Hitch's (1974) working memory model

In Section 1.2, the various systems of memory commonly accepted in the literature, and the processing of information within and between these systems, have been discussed, providing a structural overview of the broader memory system. The short-term memory system plays a central role in cognition, allowing for the encoding, storage and manipulation of sensory information, facilitating ongoing tasks, as well as interaction with long-term memories. However, while the modal memory model served as a framework for observing and quantifying these internal processes, early studies that supported the formation of this model did not provide significant insight into the processes beyond storage. The control component of cognition is suggested to be central to working memory and can be mapped to specific brain areas. A substantial body of evidence suggests that the prefrontal cortex is particularly important in exercising executive control, with the dorsolateral prefrontal cortex involved specifically in accessing, maintaining and updating memory representations and task goals (Cohen et al., 1997; Curtis & D'Esposito, 2003; Kane & Engle, 2002). It is important to note, however, that while the prefrontal cortex is crucially implicated in executive control, it is a part of a broader distributed network in which posterior regions store sensory representations and motor plans (Curtis & D'Esposito, 2003).

The basis for much of the contemporary consensus around memory in the short-term is derived from the initial work of Baddeley and Hitch (1974) who proposed a multicomponent cognitive system responsible for the short-term processing of information (Figure 1.2). Devised as an extension to concepts of short-term memory that were primarily concerned with how information was stored, and less so with the mechanisms responsible, the model has proved successful and enduring, in terms of providing insight into a vast range of cognitive phenomena, including ongoing thought and action.

Figure 1.2 Baddeley and Hitch's (1974) original working memory model (adapted from Baddeley & Hitch, 2019).

Baddeley and Hitch (1974) noted that earlier accounts agreed on the limited-capacity nature of short-term storage. However, they also highlighted that these accounts did not formally define the separate mechanisms by which working memory was utilized across and between sensory modalities. For example, in the context of the modal model (Atkinson & Schiffrin, 1968), visual short-term memory, a-v-l short-term memory, and the control processes involved in working memory were each described as operating within a general short-term store. Few processes were suggested to account for how information becomes stored in the long term beyond rehearsal and maintenance in the short term alone. Nor could the model account for how patients with short-term memory deficits were still able to learn (e.g. Shallice & Warrington, 1970). An advantage of the multicomponent model has been its use in accounting for functional cognitive processing beyond memory storage alone, extending specifically to the manipulation of information across modalities.

Baddeley (2002; 2003) described the multicomponent system as an intermediary between initial perception, long-term memory representations, and action, processes which underlie human thought. While considered a central aspect of human memory (Baddeley, 1996), emphasis was placed on the limited and somewhat fragile storage capacity of this system. As such, working memory can be viewed as an interface for moment-to-moment functioning, both in monitoring active cognitive processes and storing information temporarily (Logie, 1995; 2011; see Section 1.3.2 for further detail on Logie's workspace model of working memory).

In formulating their view, Baddeley and Hitch (1974) employed tests in which participants had to perform reading, comprehension and learning tasks while completing a concurrent digit span task intended to disrupt or occupy the capacity of short-term memory. With the digit span task thought to provide a measure of short-term capacity (i.e. the number of digits retained determined by capacity), it was expected that increased digit load would equate to increased interference, and decreased performance, in the main task. Although they did demonstrate disruptive effects of the concurrent digit span across the three types of task, this was not to the extent initially predicted, on the basis that memory for the digits would proportionally occupy available working memory resources. That is, the capacity used for digit span did not equate to the capacity to exercise cognitive processes effectively in the primary tasks. These outcomes led to the proposal of a three-component model of working memory, in order to account for the partitioning of resources during these tasks. The model consisted of separate systems for attentional control (the *central executive*), verbal-acoustic information (the *phonological loop*) and visual and spatial information (the *visuospatial sketchpad*). It is important to note here that the understanding of working memory developed below is driven primarily by behavioural data. While multicomponent models can account for a range of cognitive processes, these processes reflect the functioning of distributed neural mechanisms that map onto primarily the prefrontal and parietal cortices, which are implicated in maintaining information 'online' during tasks (D'Esposito, 2007).

1.3.1 The phonological loop

Baddeley and Hitch's (1974) initial studies informing their working memory model were conducted exclusively in the auditory/verbal/linguistic domain. To explain the findings of their 'dual-task' studies, they proposed a phonological loop, concerned with the storage and utilisation of visually and auditorily presented verbal information. This part of the multicomponent model has received the most empirical attention and development, certainly until recent years (Baddeley, 2000, 2012). A phonological store within the loop was suggested to allow temporary retention of information for an initial period of approximately 1-2 seconds. Sub-vocal articulatory rehearsal achieves encoding into the phonological store maintenance over longer periods (Baddeley. 1992), in line with earlier studies of short-term storage (see Section 1.2.4). There are key phenomena that have come to define the phonological loop and support its role as an explanatory mechanism. The *word length effect* proves a useful illustration of the relationship between memory capacity and articulatory rehearsal. Baddeley et al. (1975) found that serial recall of lists of words decreased as the number of syllables in each word increased, suggesting that the additional time required to articulate words with more syllables resulted in a more pronounced loss of words from working memory. Early studies also provided examples of the *phonological similarity effect*. Sequences of phonologically similar items are more difficult to recall than those that are phonologically dissimilar (Baddeley, 1966b). Similar sounds are also more easily confused (e.g. the letters *v* and *b*; Conrad & Hull, 1964). The phonological similarity effect suggests that verbal auditory information is the primary type of information processed in the short-term, as opposed to semantic information. Salamé and Baddeley (1982) then provided evidence that irrelevant speech can have a consistent disruptive effect on recall of visually presented digits regardless of semantic similarity, but that articulatory suppression removes this effect, resulting in reduced performance of similar levels regardless of whether there was concurrent irrelevant speech. In the first instance, this would support the view that irrelevant phonological material disrupts primary phonological material by competing for a shared limited storage space. However, an inability to rehearse (due to articulatory suppression, by which subvocal rehearsal of to-be-remembered material is reduced due to vocal articulation of irrelevant speech) results in a more severe decline in recall performance for material not otherwise subject to phonological interference, or which is typically faster to rehearse (e.g. shorter words), highlighting the crucial role of rehearsal in working memory maintenance. Evidence also suggests that an inability to rehearse will negatively impact memory for both auditorily and visually presented verbal information (Baddeley et al., 1984). Regarding the neural mapping of verbal working memory, evidence does support the distinction between rehearsal and storage components as observed in distinct responses in tasks requiring either process (e.g. Paulesu et al., 1993). Further evidence for the assertion that working memory is in part an interface between external inputs and long-term memory comes from data suggesting that the phonological loop assists in the long-term acquisition of language (Baddeley et al., 1988; Baddeley et al., 1998).

1.3.2 The visuospatial sketchpad

Although initial studies of the working memory model were based primarily in the verbal domain, it became evident that retention of visual information was susceptible to interference from secondary tasks across sensory domains (Brooks, 1967; Phillips & Christie, 1977) and more so from concurrent visual tasks than verbal tasks (Logie, Zucco & Baddeley, 1990). Evidence also suggested that a visual concurrent task does not impair a primary phonemic task as it does a primary visual task of equivalent load (Baddeley et al., 1975; as cited in Baddeley, 1983). The visuospatial sketchpad was therefore conceived as a comparable system to the phonological loop that serves the storage, maintenance and manipulation of visual and spatial material derived from sensory perception or long-term memory. Maintenance of specific information in this case is considered to rely on the successful binding of stimulus features, such as their shape, colour, location and orientation, into coherent, whole objects (e.g. Luck & Vogel, 1997; Wheeler & Treisman, 2002). In line with the concept of chunking, in the visual domain it is also necessary to bind relevant stimulus features together so that they can be represented as distinct objects or events, and also distinguished from others. In working memory, binding is thought of primarily in terms of the association of perceived features, however, associating features is also necessary in the performance of actions (binding a task with an appropriate response) and in forming long-term memories (Zimmer et al., 2006).

Distinctions have been made between the ways in which visual and spatial features are processed, which mirror the separation of phonological storage and rehearsal. Logie (1995) argued that visual images are stored passively (in a *visual cache*) while information about spatial location, and the refreshing of cache content based on this, occurs actively (via an *inner scribe*). Logie's workspace model may be broadly viewed as complimentary to the multicomponent models developed by Baddeley and colleagues (e.g. Baddeley & Hitch, 1974; Baddeley, 2012), rather than a strongly competing theoretical account (Figure 1.3).

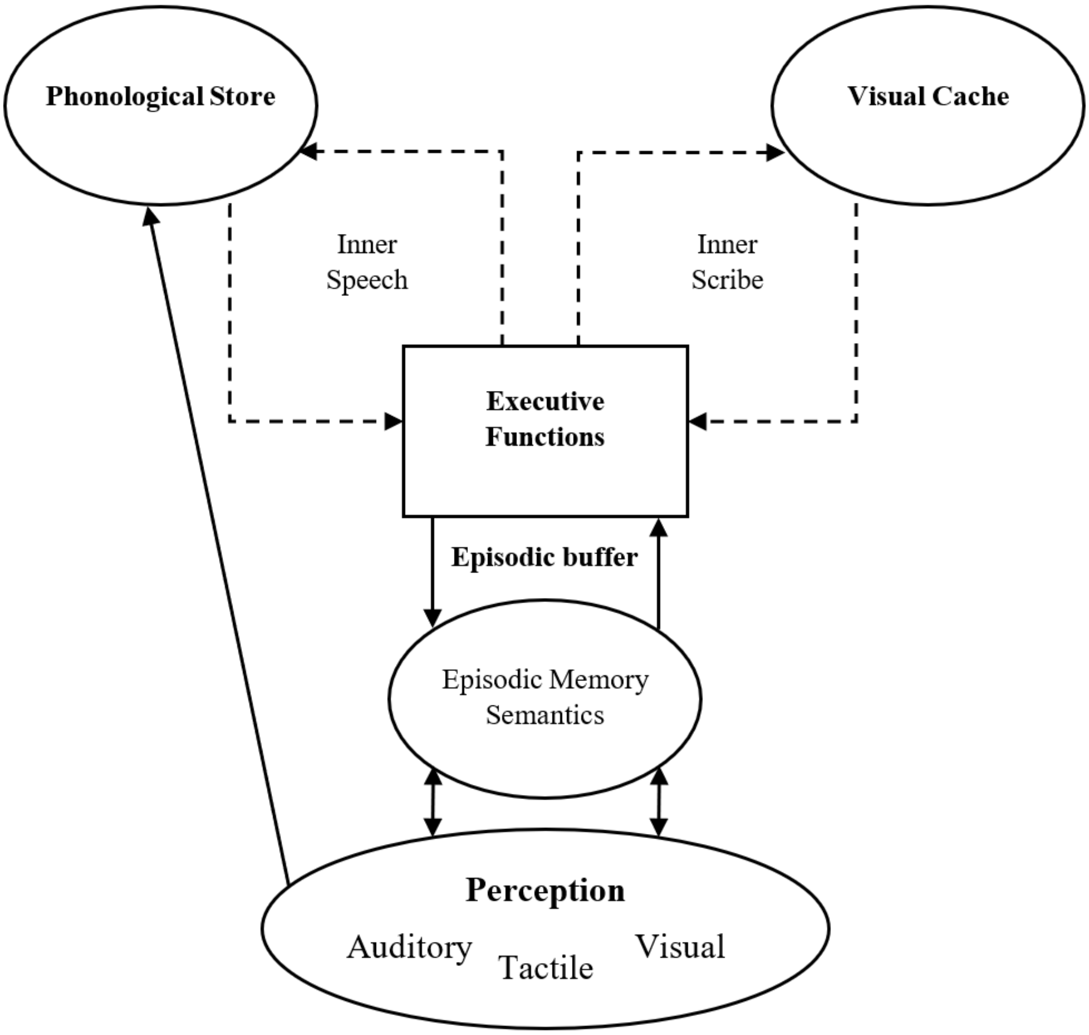

Figure 1.3 Logie's multicomponent 'workspace' model, highlighting the further specification of visuospatial working memory (adapted from Logie, 2011).

Further to this, Logie's (2011) view is that visual complexity (e.g. number of objects in a visual array/number of individual object features) and length of spatial sequences (i.e. movement in space and spatial relationships between separate objects) both determine the quality and duration of information maintenance. Interference tasks have provided support for the partitioning of each type of information within the visuospatial sketchpad. Behavioural double dissociations have been observed whereby viewing irrelevant pictures, or interfering visual noise and masks, disrupts memory for visual patterns, but not spatial locations, while performing an interfering spatial task, such as spatial tapping, disrupts memory for spatial locations, but not visual patterns (e.g. Darling et al., 2007; Della Sala et al., 1999; Quinn & McConnell, 1996). Furthermore, response accuracy to the location of targets is unaffected when participants are asked also to recall the appearance of the targets (Duff & Logie, 1999), while only small decrements are observed in dual tasking between visual memory and motor tracking tasks (Cocchini et al., 2002). As mentioned in Section 1.2, neuropsychological data also lend support to this view, suggesting a 'what' dorsal pathway that is separate from 'where' and 'how' ventral pathways (Creem & Proffitt, 2001; Kravitz et al., 2011). Logie (2011) has therefore assigned capacity limits for visual appearance primarily to the passive visual cache, and capacity limits for locations and movements to the active inner scribe, which directly interfaces with both the central executive and cache.

Despite this observed dissociation, there is also evidence for common processing capacity. Vergauwe et al. (2010) suggested that the level of general load placed upon cognition during separate visual and spatial tasks by either an intervening visual or spatial task is a better determinant of recall performance than the domain of the competing items. This would suggest that there is a shared resource that contributes to successful processing. Further discussion of visual working memory tasks, particularly those that pertain to the empirical studies conducted for the purposes of this thesis, is provided in Section 3.3.

1.3.3 The central executive

While the systems described above can account for the storage of verbal, visual and spatial information, Baddeley and Hitch (1974) also sought to account for the active processing of this information. Although less well defined than each of the modality-specific subsystems of the working memory model, the central executive provides a means by which to account for the application of attention to memory. Importantly, competing theories of short-term memory (see Section 1.3.5) do not precisely follow the idea of multiple storage components, but do share the assumption that central executive resources are a crucial part of working memory (e.g. Cowan, 1988; Kane & Engle, 2002). As opposed to defining the structure of the central executive in a manner similar to the phonological and visuospatial subsystems, the central executive can be described in terms of the individual functions attributed to it. Description of the executive functions provide a clear indication of the value of the central executive as an explanatory mechanism for interpreting the way in which information is manipulated and selected from moment-to-moment, and across sensory modalities.

Executive functions are high-level cognitive control processes responsible for guiding lower-level processes in the service of regulating thoughts and behaviours. Key executive functions identified by Miyake et al. (2000) include inhibition, shifting, and updating. Shifting refers to the ability to switch attentional focus between tasks, actions and cognitive task sets according to task demands. Inhibition refers to the ability to inhibit automatic or prepotent responses to task stimuli as required in order to avoid task disruption from irrelevant stimuli. Inhibition has also been extended to reflect the maintenance of task goals in the face of external irrelevant stimuli (Friedman & Miyake, 2017). Updating is the continued maintenance of information in working memory, involving the updating and manipulation of representations in response to new memory inputs. Where early theories of short-term memory proposed attentional filters at the early stages of memory (i.e. between sensory and short-term processing, see Section 1.2.2), the proposal of a central executive assumes that working memory is reliant on attentional control. For example, Monsell (2003) reviewed evidence that task shifting can incur performance deficits whereby newly attended tasks are performed more slowly and with more errors. This may occur due to an inability to inhibit active memory representations from the initial task (e.g. Allport et al., 1994). Being able to focus attention is also dependent on the extent to which limits are placed on perceptual and executive resources. Evidence supporting load theory (see Lavie, 2010, for a review) indicates that high perceptual load decreases the potential for irrelevant stimuli to distract participants in tests of attention, as perceptual capacity is occupied primarily with relevant material. However, irrelevant material becomes more difficult to ignore when perceptual load is low. Inhibition of irrelevant material then becomes more difficult when working memory resources are taxed, for example under dual task conditions, or other forms of interference (see also Section 2.4.2).

Despite this, being able to draw upon pre-prepared 'task-sets' from long-term memory may help to minimise disruption. Memory for visual patterns has been shown to improve when patterns are more amenable to verbal recoding (e.g. taking familiar forms such as letters or everyday objects) compared to more abstract patterns (Brown et al., 2006). Importantly, this has also been found under conditions of articulatory suppression, suggesting semantic knowledge can be drawn upon to facilitate memory when verbal rehearsal is more limited (Brown & Wesley, 2013). Furthermore, Brown and Wesley have demonstrated that participants who self-reported utilising a combination of verbal and visual strategies (rather than visual coding only) showed better general memory for visual patterns, including those that were more abstract. In the context of Logie's model, then, this evidence points to the key role of the central executive in interfacing with each modality-specific buffer store as well as long-term memory representations to facilitate the largest working memory capacity (see Darling et al., 2017; see also Gonthier, 2020, for a review in the context of visuospatial working memory). There is indeed further evidence that the central executive serves to coordinate the storage and processing of information in each modality specific store. Referring again to Cocchini et al. (2002; see Section 1.3.2), the authors presented evidence whereby participants took part in dual-task paradigms comprising combinations of a verbal memory task, a visual memory task, and a perceptuomotor tracking task (a predominantly spatial task). The tracking task had no disruptive effect on the verbal task, and only a modest disruption on the visual task. Similarly, Duff and Logie (1999) found that participants who completed concurrent serial location tracking and object identification tasks were no worse at these when performing the tasks concurrently than when performing the tasks individually. While performance dropped as the capacity required for each task increased, these results suggest that, within the capacity limits of working memory, concurrent visual and spatial memory tasks can be conducted successfully as they draw upon separate memory stores. Examining Logie's (2011) model of working memory, it would be possible to view these findings from the perspective of the central executive coordinating between encoding and retrieval of verbal, visual and spatial information.

As with memory more generally, the neuropsychological evidence points to basic functional processes that are separable but unified to a degree in performing more complex tasks. For example, inhibition, shifting and updating may all be required to plan an action, but can be probed individually via specific experimental paradigms (Miyake & Friedman, 2017). Importantly, executive functions have exhibited common activation in the prefrontal cortex, alongside the dorsal anterior cingulate and parietal cortices (Niendam et al., 2013) pointing to an overlap with the processes typically involved in working memory.

1.3.4 The episodic buffer

While successful in providing an account of cognitive phenomena relating to the manipulation of information through executive control – in both auditory and visual domains – the initial working memory model provided a limited account of how information is integrated between domains. Descriptive verbal information can be visually imagined, and visually presented verbal information can be processed phonologically. Although memory for different types of visual features may, to an extent, be a function of different processes, these features can still be associated as aspects of a single object or event. Furthermore, active memory representations may be initiated by sensory input and/or drawn from long-term storage (Barsalou, 1999). This is demonstrated by the sentence superiority effect, where recall of word lists presented as sentences is superior to that of unrelated word lists. This effect has been demonstrated for both visually based and phonologically based concurrent task conditions in which the concurrent tasks disrupted memory overall, but disrupted sentence memory to a lesser extent (Baddeley et al., 2009). This would suggest in the first instance that construing semantics can be important in bolstering short-term memory, but also that this is done through drawing upon a long-term store that is not necessarily as dependent on executive resources.

In order to account for this type of phenomena, as well as the interactive nature of the relationship between working and long-term memory, Baddeley (2000) introduced the concept of an episodic buffer in working memory (Figure 1.4). The episodic buffer can be thought of as a temporary store that allows for conscious awareness, and that reflects the limited, 4±1 capacity of working memory (e.g. Cowan, 2010). An important theoretical function was to account for the way in which features from different information sources may be 'bound' together to form complete chunks or episodes. The initial updated model, including the episodic buffer, included the assumption that binding could occur from either the input of sensory information (i.e., from the bottom up) or the individual's generation of conscious thoughts (i.e., from the top down). Initial evidence of binding arising from top-down processing suggested that the process of binding is relatively automatic and independent of working memory capacity restrictions. This evidence was derived foremost from studies in the visual domain. Luck and Vogel (1997) demonstrated that objects consisting of two features (colour and orientation) could be remembered as well as single features (colour or orientation), equating to accurate memory for 16 individual features across 4 discrete objects. This 'four-chunk' visual working memory capacity limit was also found in recall of objects consisting of four features compared to recall of objects consisting of single features (Vogel et al., 2001).

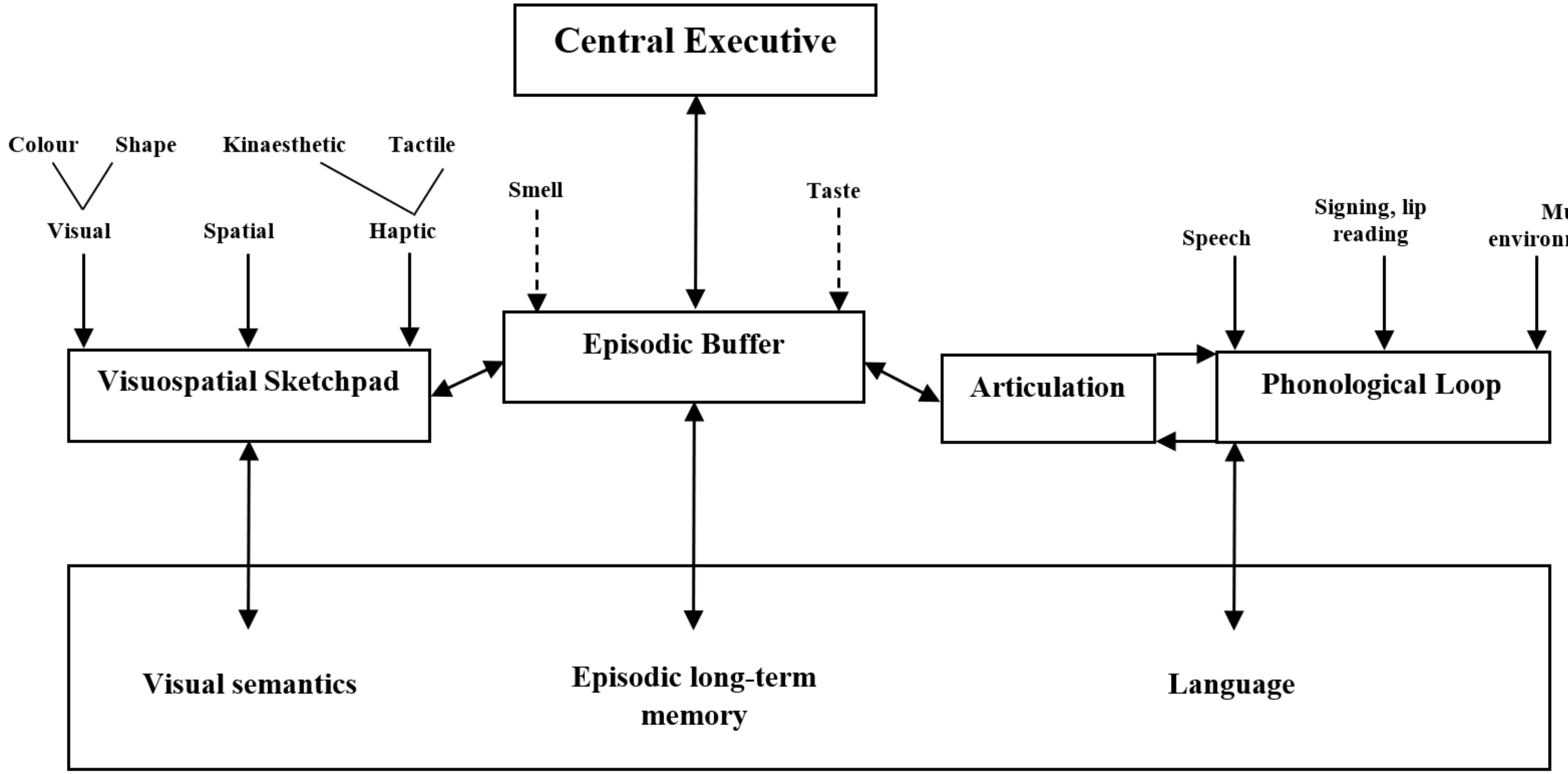

Figure 1.4 The most recent version of the multicomponent working memory model, adapted from Baddeley (2012) and Darling et al. (2017). This includes the episodic buffer proposed by Baddeley (2000) and demonstrates the links between working memory and long-term memory.

While a much more recent and, as such, relatively underdeveloped concept within the multicomponent framework of working memory, the concept of an episodic buffer presents a useful theoretical mechanism that accounts for the role of attentional processes in this system, as well as another means by which short-term and long-term memory interact. The concept of feature binding has offered increased opportunity to further understanding the processes by which information is effectively and efficiently utilised, specifically in visual working memory (see Section 1.4.1). It has done so specifically by emphasising the importance of attention. If working memory operates at the centre of the broader memory system, which provides much of the basis for cognition, then it may be said that attention increasingly appears vital in driving cognition via its effects on working memory contents. Attention plays a key role in focusing and sustaining visual cognition and short-term processing over space, quantities, and time.

1.3.5 Alternatives to the multicomponent model

Baddeley (2002; 2010) has argued that the value in modelling working memory is in allowing for the development of knowledge of a wide range of cognitive control and information manipulation processes, set against a testable, structural framework. Given the aim of the research reported in this thesis is to understand the effects that anxiety has on visual working memory through attention, the approach taken in the studies reported in Chapters 4-7 was informed foremost by the multicomponent working memory model. This was in light of the fact that this model presents a wide-ranging explanatory system for the relationships between attention and working memory that has been the most influential in informing contemporary research in short-term memory. However, while arguably the most successful working memory model, the multicomponent model is not universally accepted, and alternative models can provide further insight into the relationship between working memory and attention. As will be discussed below (Section 1.4), current theories appear to be informed foremost by the multicomponent approach, but also by these alternative accounts.

One such alternative is the embedded processes model of working memory (Cowan, 1988). This model is useful in accounting for the processes by which external stimuli enter working memory and interact with attentional control to inform task responses. Crucially, from this perspective, short-term memory represents activated long-term memory representations. Working memory represents the relationship between the material temporarily activated as short-term memory and the executive functions employed to focus attention on a specific subset of activated material. In terms of the processes themselves, external stimuli are argued to enter a brief sensory store (in line with the modal model, see Section 1.2.1) after which they become active in short-term storage and may also activate long-term memories. Central executive control can then focus attention upon either external stimuli or activated representations. From here, voluntarily controlled or automated responses are made. It is useful to bear this perspective in mind when approaching the relationship between attention and working memory. The embedded processes model does not include assumptions about modality specific storage as the multicomponent model does. Instead it includes general assumptions about how attention may voluntarily or involuntarily be drawn to external stimuli and long-term memories in order to formulate appropriate task responses that become active in a narrow focus of the individual's attention. Oberauer (2002) proposed more specific limitations within this system: a first level of activated long-term memory, within which there is an activated region that holds a limited number of items available for attentional focus, and the focus of attention itself, with a capacity limit of one memory item. Nee and Jonides (2013) have proposed a similar view in support of this function of attention based on neuropsychological data. It is important to note that this perspective is not incompatible with the multicomponent model. The embedded processes view is primarily concerned with the processes of the memory system in a short-term memory task, and the multicomponent model focuses on detailing the components by which stimuli of different modalities may be separable and accessed for short-term use.

Another perspective defines working memory as controlled attention, separating working memory from short-term memory (Engle et al., 1999; Engle, 2002; Kane & Engle, 2002). Despite operating under a similar assumption to the multicomponent model with respect to separable domain-specific short-term buffer stores, these are considered separate from working memory itself. From this view, working memory capacity may be viewed as the culmination of attentional control processes across the short-term domains, and thus vary between individuals according to their attentional control abilities (Engle et al., 1999). Working memory, according to Engle (2002), serves short-term memory, but is distinct in that higher working memory capacity means more items can be focused on or blocked from the focus of active attention, rather than passive storage akin to short-term memory. This view was formulated on the basis of evidence that working memory capacity, as measured by the complex span task (which explicitly measures both processing and storage of information; Daneman & Carpenter, 1980), predicts a range of cognitive functions. These include comprehension, orienting, learning, writing, and reasoning (Engle, 2002). It is therefore plausible that there is an underlying common function of working memory capacity in cognition, interpreted by Engle as closely related, or in fact synonymous with, 'fluid' intelligence and executive functions. The most recent account of this view is that working memory capacity reflects the ability to maintain information online in the face of distraction, and fluid intelligence as the ability to draw on potentially pertinent information from long-term memory and to disengage from it as required (Engle, 2018).

Logie's (1995; 2011) model of working memory (Figure 1.3) may represent an intermediary between these perspectives, suggesting that perceived stimuli can enter short-term storage independently of long-term memory, but can also automatically activate knowledge representations (i.e., episodic and semantic long-term memory). The central executive, from this perspective, is then responsible for integrating material from the short-term buffer stores and the long-term knowledge base. Logie's model is particularly useful for understanding working memory in the visual domain, as it explicitly acknowledges the fact that both long-term memories and sensory information will inform task responses. It also emphasises that sensory information can automatically activate long-term knowledge, while also accounting for the distinct nature of verbal and visuospatial processing. Further to this, it assumes that working memory capacity is a function of attention as well as specialised storage processes.

It is important also to refer briefly to the neuroanatomy of attention at this stage, in order to contextualize the use of theoretical models in describing attention and working memory processes. Posner and Rothbart (2007) have reviewed the significant body of evidence indicating the existence of large-scale neural networks that are responsible for three key attentional functions. ‘Alerting’ refers to the degree of attentional sensitivity/receptivity to incoming sensory information. The alerting network is associated with thalamic, frontal and parietal brain regions. ‘Orienting’ refers to the direction of attention towards information sources, and is associated with posterior brain regions. ‘Executive attention’ refers to the mechanisms responsible for resolving concurrent conflicting cognitions and action responses, and has been associated with the anterior cingulate and lateral prefrontal cortices. Thus, when discussing the processes by which attention is allocated to information, and by which information is maintained within attentional focus, it is important to bear in mind that these processes are the product of interacting attentional networks at the neuropsychological level. As such, models of working memory seek to account for the outcomes of these network processes via interacting explanatory mechanisms.

The multicomponent model remains a particularly useful frame of reference for the relationship between executive and perceptual processes, especially as it has provided further insight into visual working memory in recent years. The embedded processes perspective provides a particularly useful account of the scope and function of attention, and capacity limits in working memory. Meanwhile, the view of working memory as controlled attention acknowledges that working memory may be reliant on attentional processing, which is important to bear in mind when considering recent findings in the visual working memory literature (see Section 1.4.1). While there are still other theoretical accounts of short-term memory available, each theory briefly described here focuses on different cognitive processes that may complement the others, with respect to providing a comprehensive account of what constitutes working memory (Logie, 2011).

1.4 Visual working memory and attention

Throughout the experiments reported in this thesis, the term ‘visual working memory’ refers to the group of cognitive processes responsible for the short-term encoding, processing, storage, maintenance and recall of visual information (Baddeley, 1992; 2012). Theories converge on the notion that visual working memory is limited in capacity regarding the amount of information that can be processed at once (Cowan, 2010) as well as over time (Wheeler & Treisman, 2002). Extending the views of Logie (2011; see Section 1.3.2) regarding visuospatial processing, Pertzov et al. (2017) argue that competition between multiple memory items, and decay of representations over time, are both required for rapid forgetting to occur in working memory. This in turn reflects a similar limit to the amount of information that can be actively attended to or prioritised at a given time.

Chun (2011) has suggested that visual working memory encoding and maintenance is a result of sustained attention to visual stimuli. More specifically, Chun et al. (2011) argued that successful sustained attention and working memory processing are dependent on the ability to inhibit internal, cognitive distractors and external perceptual distractors. Bleckley et al. (2015) have similarly defined working memory capacity not only as the amount of information that can be processed simultaneously in the immediate term, but also the ability to maintain this information despite distraction. Sustained attention is the process by which information enters and is maintained within the *focus of attention*, which reflects the most immediate processing of information in visual working memory (Cowan et al., 2005). Outside of the multicomponent working memory model (e.g. Baddeley, 2012) the focus of attention has been interpreted as a distinct level of working memory responsible for selecting information held in temporary storage for direct access (e.g. Cowan, 1988; Nee & Jonides, 2013; Oberauer, 2002). With respect to the development of the Baddeley and Hitch (1974) model of working memory, Hu et al. (2014) have proposed a *privileged state* in which items are most accessible for recall with direct access to conscious awareness but are simultaneously vulnerable to interference. Originally more analogous to the focus of attention, further distinctions have since been made such that they are treated as separate components, at least in the context of the paradigms described in Chapter 3 of this thesis.

Information may be brought into the focus of attention in a goal-directed or stimulus-driven fashion. In the case of goal-directed attention, participants may employ strategies to select information (e.g. Hu et al., 2014). For stimulus-driven attention, stimuli may gain increased salience via cuing, such as changes in features (e.g. Zokaei et al., 2014), or their emotional valence (Mather, 2007). These concepts are in line with the view of Chun et al.'s (2011), who argued that maintenance of information in attentional focus is dependent on relative contributions of consciously-guided executive control – as directed by a central executive working memory component – and immediate perceptual processing. Chun et al.'s view has roots in an influential narrative review by Corbetta and Shulman (2002, see also Yantis & Egeth, 1997). They argued that top-down factors, such as knowledge, expectations and objectives, and bottom-up factors relating to sensory inputs, were distinct systems that interactively determined the control of visual attention. Specifically, they suggested that the bottom-up system serves as a 'circuit-breaker' for the top-down system that detects and alerts towards relevant external stimuli. In Chapter 2, which details the relationship between anxiety, attention and working memory, the notion of a perceptual filter – or variations in the likelihood of stimulus detections at this level – is used to explain the impacts of anxiety on cognitive processing.

1.4.1 Feature binding in visual working memory

Optimal working memory processing has been demonstrated to rely on binding processes, whereby more features or individual items can be remembered if they are coded as discrete units. In the visual domain, there has been inconsistent evidence surrounding whether associating individual features as whole objects is dependent on attention, or is subject to interference, presentation, and strategy effects. The role of attention in facilitating visual working memory performance has largely been supported in studies employing visual feature binding paradigms. In these tasks participants are typically presented with sequential or simultaneous arrays of 3-5 items, usually consisting of 2 features each (e.g., shape and colour). Memory is then tested for an array item either by change detection (recognition) or cued recall. Early research on binding typically involved simultaneously presented arrays and provided mixed evidence regarding the role of attention in the binding process (Luck & Vogel, 1997; Wheeler & Treisman, 2002). Results from sequential tasks have since demonstrated a consistent serial position curve (see also Section 1.2.4) in memory performance. Mid-sequence items are remembered less successfully than items at the beginning of the sequence, which in turn are remembered less successfully than items at the end of sequence (Allen et al., 2006, 2014; Hu et al., 2014, 2016). It has also been shown that later items can be overwritten by the presentation of a subsequent irrelevant visual distractor (Allen et al., 2015; Hu et al., 2016; Ueno, Allen et al., 2011; Ueno, Mate et al., 2011). This suggests that a privileged state in working memory is partly a reflection of the recency with which the items were encountered. Those encountered most recently are processed relatively cost-free and without attentional processing but remain fragile when followed by additional stimuli. The consistency with which memory for bound objects decreases following the presentation of subsequent stimuli would suggest that while attention is not an inherent requirement for binding, it is required for maintaining bindings over time, and in the face of distraction. As such, it is useful to characterise visual working memory as comprising components analogous to Logie's concepts of the passive visual cache, for holding information, and the active inner scribe, for drawing upon the central executive to monitor and maintain information across time (see also Pertzov et al., 2017).

It seems that memory decline for earlier items can be reduced by the volitional control of attention toward them (Hu et al., 2014). However, Hu et al. (2016; Experiment 1) have also shown that this ability is reduced when participants are under high cognitive load (e.g. backwards counting vs number repetition), with end-sequence items typically free from this disruption (see also Allen et al., 2014). In a second experiment, they found that reduction in memory accuracy due to suffix interference effects (i.e. the presentation of an irrelevant stimulus at the end of a memory array) is consistent in the same paradigm, independent of cognitive load. Thus it would appear that perceptual selective attention serves as the entry point to visual working memory while executive control can be used to actively maintain information encoded into visual working memory. Hitch et al. (2020) have most recently updated the visual working memory model based on these recent findings from binding studies (see Figure 1.5).

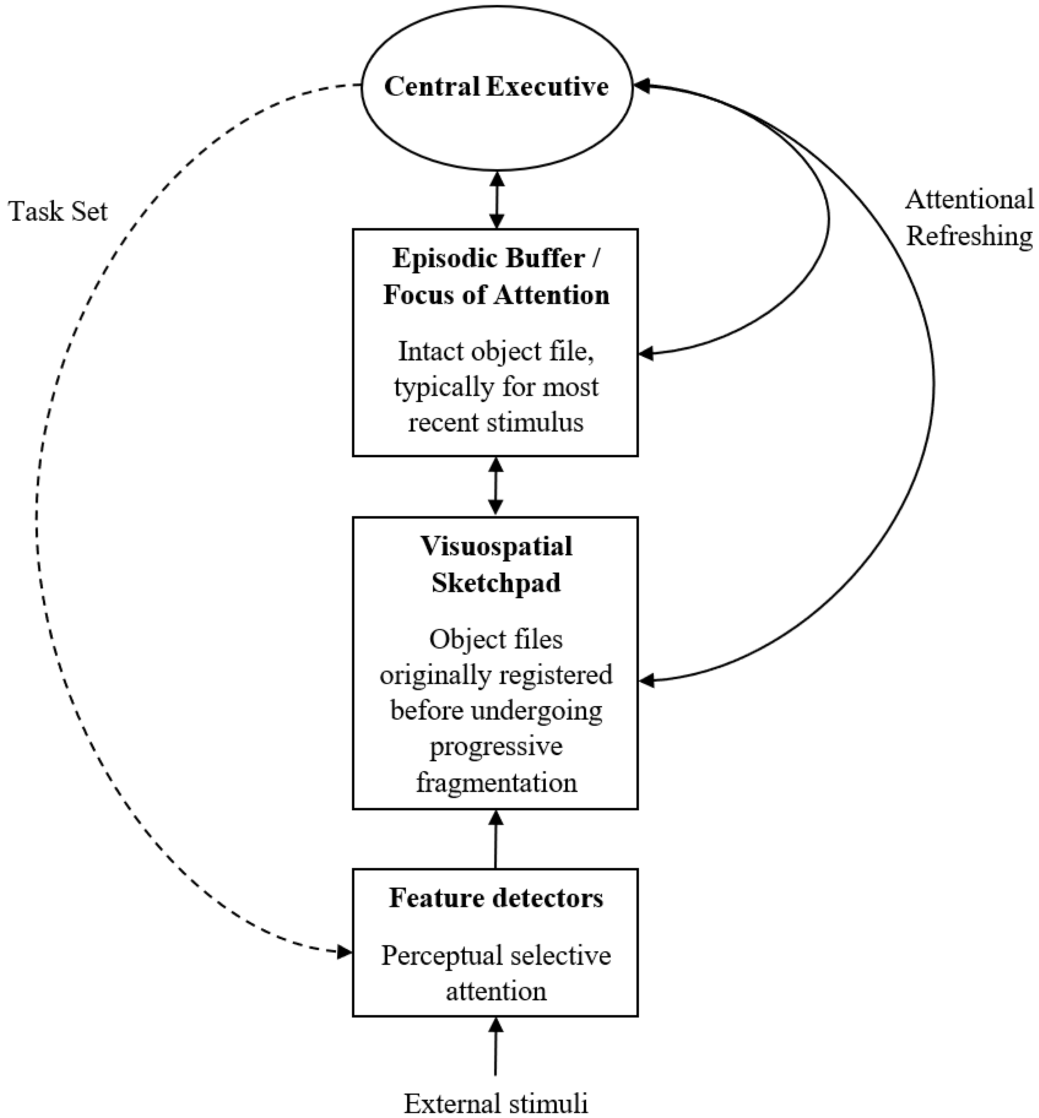

Figure 1.5 The main components of visual working memory and their associated functions outlined by (and adapted from) Hitch et al. (2020).

Broadly, evidence suggests executive attention is required for the continued maintenance of visual information for subsequent recall, and the effectiveness of top-down attention processes is, in part, contingent on information encountered at initial perception. Taken together, visual information that is given priority either via intentional direction of attention toward it, or by virtue of its perceptual recency (i.e. capture from bottom-up attention), is most readily accessible for recall. However, it is also more prone to being overwritten by subsequent information. Processing of information in visual working memory should therefore be thought of as a product of the interaction between top-down and bottom-up attention processes.

1.4.2 Present definition of working memory

It is useful to conclude this chapter by providing a description of the specific way in which working memory is conceptualised throughout the remainder of this thesis. This is given that researchers may draw on multiple definitions simultaneously (Cowan, 2017). This thesis reports data gathered from experimental investigations using tasks that assess specifically visual working memory. These investigations were primarily based on Hu et al.'s (2014; see also Hitch et al., 2020) suggestion of a broad framework for visual working memory, in which a central executive is responsible for guiding attention within working memory. Within this framework, the central executive is also responsible for monitoring a perceptual filter, effectively a bottom-up attentional selection component. A focus of attention, in line with the concept proposed by Cowan (1988), Oberauer (2002), and Nee and Jonides (2013), is the product of each of these and is responsible for selecting information active within working memory. To this extent, working memory may be viewed as reliant on focused attention, if not synonymous with it as suggested by Kane, Engle and colleagues (e.g. Kane & Engle, 2002; Engle, 2018). In the context of the binding tasks used, it is from the focus of attention – the product of both executive and perceptual attention – that stimuli are selected for task responses. The potential role of anxiety in impacting these attentional processes, and subsequent performance of visual working memory, is proposed in Chapter 2.

1.5 Chapter Summary

Cognition encompasses the processes responsible for everyday perception, memory, and action. The processes involved at each stage, from both top-down and bottom-up perspectives, can be explained by modelling memory in terms of distinct components that account for a vast range of observable cognitive phenomena in the short to long term. Working memory has been described as being at the centre of cognition. It is responsible for the accumulation and integration of memory features prior to their consolidation in long-term memory. Working memory is representative of the processes that are responsible for the short-term processing of information, whether from the senses or activated from long-term memory, and that facilitate the performance of cognitive tasks.

From the perspective of multicomponent working memory models, verbal and visuospatial working memory are separable but both rely on common processing resources. These common processes may be viewed as the processes of attention. Attentional control processes are particularly important for keeping information ‘online’, orienting to tasks or stimuli in the environment, and inhibiting distraction. Recent literature from the study of feature binding has helped to better clarify the contributions of attention (at both the perceptual and executive level) to visual working memory. Importantly, these paradigms allow for the manipulation of factors influencing attentional control, further probing their effect on memory. The specific paradigms drawn upon in the experiments of this thesis will be given detailed discussion in Chapter 3. These paradigms present a novel means of assessing the influence of a variety of individual differences on cognitive performance. For example, with particular success in the study of cognitive aging and neuropsychological deficits.

In Chapter 2, the impact of emotion on cognition will first be given specific consideration. There has been much in the way of theoretical framework development to account for the ways in which anxiety may impact cognition. However, there has been limited insight as to how this could be explained by or incorporated within models of working memory, particularly regarding the visual domain. As such, there is a clear opportunity to utilise established visual working memory theory and paradigms to better determine the effects of anxiety on working memory.

2 Anxiety, attention and working memory

2.1 Chapter overview

One cause of individual differences in working memory is emotion, such as the emotional valence of external stimuli, emotional disposition and states, or an interaction between these. However, we require a clear explanation of the impact of emotion on cognition from the perspective of the multicomponent model of working memory (e.g. Baddeley, 2012). This chapter will focus primarily on cognitive theories of anxiety. These theories posit a relationship between anxiety and attention. As described throughout Chapter 1, attention plays a key role in working memory across the verbal and visuospatial domains. The impact of anxiety on attention therefore presents a means of exploring the broader impact of emotion on working memory. The chapter begins by introducing anxiety with a focus on highlighting the specific facets of anxiety which inform the working definition used in this thesis. Consideration will then be given to theory and empirical evidence surrounding the relationship between anxiety and cognitive processing, and specifically those that indicate a relationship with working memory functioning. The case will be made that the visual working memory framework, developed in part from recent studies of visual feature binding, first presents a means of better investigating and understanding the impact of anxiety on attention and working memory ability. Also, it allows us to assess the extent to which prominent working memory theories may be refined to account for the role of emotion. These issues will provide background for the methodological approach taken (summarised in Chapter 3) in the experimental studies that form the data chapters of this thesis.

2.2 Anxiety

2.2.1 Anxiety as a multidimensional construct

Anxiety can be defined broadly by at least two separable experiential components. The first component is cognitive worry/apprehension. This is trait level anxiety akin to an enduring propensity for repetitive, negative thinking as well as an increased tendency to experience states of worry. The second component consists of somatic (i.e. physiological) states of arousal and tension in response to stressful situations (Moran, 2016). Eysenck (1982) previously separated trait and state anxiety by the nature of the internal and external factors influencing the degree of an individual's experience of anxiety. According to Eysenck (1982), trait anxiety reflects general susceptibility to anxiety and state anxiety reflects the severity of external threat and/or stress. State anxiety, from this perspective, should not vary greatly between individuals reporting high and low levels of trait anxiety, but trait differences will be better reflected in state differences as the degree of external threat or stress increases. That is, state anxiety is determined both by trait anxiety as well as these external factors. This view speaks to the proximal nature of anxious responses, that is, worry/apprehension regarding future events, and reactive fear/tension in response to present threats and stressors. However, cognitive and somatic symptoms have been, and continue to be, reliably measured at both the trait and state level. In an initial factor analysis of the Beck Anxiety Inventory (BAI; a commonly used self-report measure of anxiety experienced "in the past week”), Beck et al. (1988) found support for a two-factor structure consisting of cognitive and somatic anxiety dimensions. The two-factor structure has received further support in subsequent psychometric studies of the BAI (e.g. Hewitt & Norton, 1993; Kabacoff et al., 1997), and has been formalised in the development of separate cognitive and somatic subscales in other anxiety measures. For example, l'Échelle d'Anxiété d'Évaluation État (EAEE; Beaudoin & Desrichard, 2009) – or State Test Anxiety Scale - has been used to measure cognitive and somatic anxiety separately in test situations. The State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree et al., 2008; see Section 3.2.3) is a measure assessing symptom levels ‘in general’ and ‘at this very moment’. Sharp et al. (2015) have further categorised trait anxiety along these lines, delineating *anxious apprehension* as well as *anxious arousal*. Anxious arousal reflects enduring hypervigilance as well as the propensity to experience somatic hyperarousal to mild stressors.

Thus far the limited, but increasing, number of studies that have separated cognitive and somatic anxiety have shown that effects of anxiety on cognitive performance more reliably manifest from the cognitive, rather than somatic dimension (see Section 3.2.2). Theory and empirical evidence converge on the notion that anxiety can be separated into measurable cognitive and somatic dimensions. While the cognitive dimension may be more readily aligned with trait anxiety, and the somatic dimension with the experience of anxious states, both cognitive and somatic anxiety can be measured at both trait and state level.

2.2.2 Neural basis of anxiety

Neurological data from studies of patients experiencing clinical anxiety disorders further informs how anxious experiences occur, as well as their impact on cognitive processing. Generally, anxiety disorders are associated with impairments in specific neural circuits, beginning with hyperactivation of the amygdala, which is crucial in the formation and retrieval of emotional memories (Ressler & Mayberg, 2007). Hyperactivity in the amygdala and insula has been observed across post-traumatic stress disorder, social anxiety disorder, and specific phobia (Etkin et al., 2007).

In non-patient populations, the amygdala has been associated with salience processing, rather than executive control, across distinct neural networks (Seeley et al., 2007). In Generalised Anxiety Disorder (GAD), there is evidence of amygdala activation in connection with the executive control network (prefrontal, parietal and inferior occipito-temporal cortices) when at rest, which is not present in healthy controls (Etkin et al., 2009). Etkin et al. (2009) have argued that this physiological activation represents functioning of a compensatory cognitive control network drawn upon to regulate experiences of anxiety. This has also been observed in tasks in which emotional conflict must be regulated (Etkin et al., 2010; Etkin & Schatzberg, 2011). Greater dorsolateral prefrontal cortex activation has also been observed in GAD patients during processing of emotional expressions (Blair et al., 2008).

Changes in activity associated with anxiety extend to a greater reduction in default mode network activity. This has been demonstrated during tasks involving emotional stimuli in anxiety patients compared to controls, specifically in the medial prefrontal and posterior cingulate cortices, which are implicated in emotion processing (Zhao et al., 2007). GAD patients have been shown to have increased connectivity between the amygdala and executive control networks compared with non-patients, even those with a high tendency to worry (Porta-Casteràs et al., 2020). Burdwood et al. (2016) have also found neural evidence for the distinction between anxious apprehension and arousal in a non-patient sample. In their study, apprehension and arousal were found to associate differently with default mode network activation. At higher levels of anxious apprehension, reduced connectivity between the posterior cingulate cortex and other regions reflect a decrease in internally focused thought. Whereas, at higher levels of anxious arousal, increased activity reflects greater focus of attention, potentially towards monitoring anxious physiological responses.

2.2.3 Practical impacts of anxiety

It is evident that clinical and non-clinical anxiety are associated with aberrant activity in neural networks responsible for cognition. Importantly, though, anxiety has also been associated with reduced behavioural performance in cognitive tasks in both patient and non-patient samples, the latter of which is the focus of this thesis (see Sections 2.3 – 2.6). Moreover, there is a large body of evidence that suggests that clinical anxiety disorders are widespread, debilitating for patients, and incur high costs in health and social care (e.g., Leon et al., 1995; Revicki et al., 2012; Toghanian et al., 2014; Wittchen, 2002). There is also evidence that individuals who experience anxiety to a degree that does not meet criteria for a clinical diagnosis are similarly impaired in day-to-day functioning (e.g., Haller et al., 2014; Kertz & Woodruff-Borden, 2011). Better understanding of the cognitive impacts of anxiety within the latter group can help to highlight the specific functional impacts of anxiety on everyday life.

Looking first to clinical anxiety disorders, cumulative data from 28 countries has demonstrated that anxiety disorders are the most prevalent type of DSM-IV classified mental disorder, with recent global prevalence estimated at between 4.8% to 10.8% (Stein et al., 2017). In the UK, the estimated 12-month prevalence of diagnosed anxiety disorder cases has been estimated at 18.2% of the population (over 8 million cases) in 2010 (Fineberg et al., 2013). Data from the same report suggests the total UK cost of anxiety disorders in 2010 was over £11bn, placing anxiety disorders as the 4th most costly disorder of the brain in that year. Global self-report data from respondents in both developing and developed countries has indicated that mental health disorders, including anxiety disorders, are overall more personally, professionally, and socially disabling than physical disorders (Ormel et al., 2008). Anxiety disorders are also associated with lower overall quality of life (Hoffman et al., 2008). Further data from the US points to the relative severity of anxiety disorders, with 22.8% of 12-month prevalence amongst a national representative sample being classified as severe, 33.7% as moderate, and 43.5% as mild (Kessler et al., 2005). Rates may also fluctuate according to specific stressors. For example, Twenge and Joiner (2020) have recently reported that depression and anxiety disorder diagnoses were three times as likely to occur at the onset of the COVID-19 pandemic in March-April 2020 than in the same monthly period in 2019.

Classification of anxiety severity is particularly important in understanding its impact on livelihood. Experience of GAD symptoms below the threshold for clinical diagnosis has been shown to be twice as prevalent as the experience of the disorder itself (Haller et al., 2014). Psychological, social and professional functioning are impaired to a greater degree within this population than individuals who may be considered non-anxious (Haller et al., 2014). Reduced quality of life has been found across groups presenting sub-threshold GAD and reporting high levels of worry as compared to a control group (Kertz & Woodruff-Borden, 2011). They also report poorer perceived physical health, poorer perceived social support, higher levels of stress, and reduced sleep (Kertz & Woodruff-Borden, 2011). Sub-threshold symptoms were also found to be a predictor of eventual diagnosis of an anxiety disorder (Karsten et al., 2011), including within a university sample (Kanuri et al., 2015).

Data therefore points to anxiety as a prevalent and debilitating mental health phenomenon that has potentially significant negative impacts on quality of life. Indeed, recent meta-analyses have found an anxiety prevalence rates in the general population to be 25-39% in Asian and European countries following the onset of the COVID-19 pandemic (Luo et al., 2020; Salari et al., 2020). As these effects of anxiety are also true of both diagnosed and subthreshold anxiety, it is of interest to understand the means by which anxiety impacts on cognitive functions, which play a central role in to day-to-day functioning.

2.3 Incorporating emotion in working memory models

2.3.1 Anxiety and depression

Eysenck (1982) drew attention to the fact that the relationship between emotion and cognition, as well as motivation, had received limited theoretical attention in earlier literature. Critical of theories of information processing that modelled cognition on the performance of achieving single task goals, he proposed that cognitive processes were dynamically affected by motivational and emotional arousal in response to internal and external stimuli. Baddeley (2007) identified anxiety and depression as two types of emotion that bear clear relevance to the multicomponent working memory model (see Section 1.3). These two emotions also share some overlap. Ninety percent of patients with anxiety disorders have been reported to experience comorbid clinical depression and there is overlap in the neural circuitry, symptoms and treatments involved in each emotion (Gorman, 1996; Ressler & Mayberg, 2007). Anxiety and depression are also both associated with repetitive thinking focused on negative experiences and the meaning of these experiences (Nolen-Hoeksema, 2000). However, while repetitive negative thinking is common to both anxiety and depression, these manifest in separable, if not wholly distinct, experiences of worry and rumination. As highlighted in Section 2.2.1, worry is characteristic of anxiety, and typically relates to negative thoughts of future events (or the implications of past events on the future) whereas rumination – more typical of depression - is related more to repetitive negative thinking on past events and why they have happened (Nolen-Hoeksema et al., 2008).

Baddeley (e.g. 2007; 2013) has reviewed a range of evidence that the cognitive impacts of anxiety and depression occur at different stages within working memory processing. Anxiety appears to impact on cognitive processes primarily through executive control, specifically the malfunctioning of attentional alerting and orienting (see Sections 2.3 – 2.5). The effects of depression, meanwhile, seem to be broader. In a study comparing anxious and depressed participants, depression has been shown to affect the visual, verbal, and executive components of the multicomponent working memory model, with anxiety suggested only to be associated with a comparable effect on central executive functions (Christopher & MacDonald, 2005). This may be attributable to the distinct profile of each type of affect. Factor and cluster analyses of a nation-wide representative German sample has provided evidence for a four-variable model of negative affectivity. According to this view, anxiety is characterised by higher self-reported scores of emotionality (anxious arousal) and worry, but average scores of anhedonia (the absence of positive affect) and dysthymia (depressed mood), the defining features of depression (Renner et al., 2018). Evidence from the same analyses suggests that this difference between levels of emotionality and worry on one hand, and dysthymia and anhedonia on the other, is more pronounced in participants with Generalized anxiety disorder. These data fit with the view that anxiety primarily affects executive control and pre-attentional mechanisms. They do however provide less direct support for Baddeley’s view that depression influences a decision-making mechanism (a ‘hedonic detector’) based on a resting or induced emotional state. The particular mechanistic effects of depression on working memory are outside the scope of this thesis. However, they do serve as a comparison which indicates the specific nature of the effects of anxiety on attention and working memory, and the potential need to separate different types of negative affect when exploring these.

2.3.2 Anxiety and the multicomponent model

A small number of studies have explicitly examined the relationship between anxiety and Baddeley and Hitch’s (1974) multicomponent working memory model. Eysenck et al. (2005) investigated the impact of trait anxiety on performance of the Corsi block-tapping test (Corsi, 1972; see Section 3.3.1 for further methodological detail). While generally viewed as a test involving executive functions, visuospatial processing, and short-term memory, Eysenck et al. manipulated this task further to include various concurrent tasks. A backwards counting task was used to probe executive functions, a spatial tapping task was used to probe visuospatial sketchpad processing, and an articulatory suppression task was used to engage the phonological loop. Differences across conditions were only observed when participants performed the backwards counting task, but not the spatial tapping or articulatory suppression task. It may therefore be suggested that these results were an indication that anxiety impacts working memory only through the central executive, not the phonological or visuospatial components. Christopher and MacDonald (2005; see also Section 2.3.1) also compared performance between depression patients, anxiety patients, and a control group on a battery of tests assessing visuospatial, phonological and executive processes. Their results demonstrated distinct profiles of performance between depressed and anxious patients. Compared to controls, the depressed patients were impaired across working memory domains. In contrast, the anxious patients were impaired only in tasks reliant on the central executive and performed comparably to controls in the phonological and visuospatial domains. Meanwhile, using a similar approach in a non-clinical sample, Walkenhorst and Crowe (2009) did not find any significant negative effects of high trait anxiety in tasks involving any of the working memory components. In fact, their results showed shorter response latencies in visuospatial and verbal tasks at high levels of state worry and/or trait anxiety, suggesting the possibility that high levels of anxiety may benefit cognitive task performance.

On the basis of these results, it may appear feasible to suggest that there are limited effects of anxiety, at both clinical and subclinical level, on the visuospatial and verbal components of of the multicomponent working memory model. However, Baddeley (2013) has argued that one can readily account for effects of anxiety on cognition within the multicomponent model, providing that researchers assume working memory is influenced by both a perceptual attentional filter as well as executive attention (see Section 1.4, Figure 1.5). That is, a disruptive effect of anxiety on cognition, and working memory specifically, should be observable primarily through the disruption of attentional control. There is indeed a longstanding literature base that supports this view. Theories of the link between anxiety and cognition have developed primarily through the study of attentional processes. More recently, theories of anxiety have drawn upon concepts that are central to the present understanding of visual working memory (see Section 1.4). As research indicates a need to account for the mechanisms by which information is integrated across modalities in working memory (see Section 1.3), so too is there a need to determine how anxiety influences the various components of working memory. The development of this literature base is detailed throughout the remainder of this chapter.

2.3.3 Early theories of anxiety and attention to threat

Evidence indicates that the emotional content of stimuli can influence attentional processing. Fear-relevant (or threat-relevant) images such as spiders or snakes are detected more quickly in visual search than fear-irrelevant images such as flowers and mushrooms (Öhman et al., 2001). The effects of emotional stimuli appear to be driven by anxiety levels. People experiencing high levels of state anxiety, even at subclinical levels, struggle to disengage from threatening words and faces to detect task-relevant targets (Fox et al., 2001). High trait anxiety has also been associated with increased dwelling on positive and negative emotional faces compared to neutral, as well being associated with higher levels of state anxiety (Fox et al., 2002). These results indicate that trait anxiety may underlie attentional biases in laboratory-based cognitive tasks, either directly or through influencing higher state anxiety.

These findings reflect early theories of the relationship between anxiety and cognition, particularly those of Williams et al. (1988) and Mogg and Bradley (1998), which were primarily concerned with how threat may affect cognitive processing at high levels of anxiety. Despite this specific focus on threat, the theories established concepts in the emotion-cognition literature that bear direct relevance to general theories of attentional control and short-term memory. The theories were driven by evidence for a processing bias for threat-related information. Faster responses to probe stimuli appearing in the location where threatening information had originally been presented, compared to neutral information, suggested that threatening information selectively captured attention (Broadbent & Broadbent, 1988; Macleod et al., 1986; Mathews & Macleod, 1988). Furthermore, evidence demonstrated slowed performance in timed tasks in the presence of threatening distractors, particularly slower Stroop task performance in highly anxious participants for threat-related over neutral words (Mathews & MacLeod, 1985; Williams et al., 1996). This result points to a difficulty for anxious participants to disengage from or ignore threatening stimuli. Williams et al. (1988) initially suggested that excessive allocation of attention to threat was dependent firstly on an Affective Decision Mechanism, which determined the threat value of a stimulus based on levels of state anxiety. Biased processing for information that was deemed threatening was then dependent on levels of trait anxiety via a Resource Allocation Mechanism. Higher levels of trait anxiety were thought to result in a greater proportion of resources being directed towards stimuli with a higher threat value, and lower anxiety resulting in attention being directed away from threat.

Mogg and Bradley (1998) similarly delineated an initial system responsible for threat evaluation (a valence evaluation system) and subsequent trait-driven system responsible for engaging with stimuli (a goal engagement system). Where their theory differed was in the causal factors of anxiety-related processing decrements. From their perspective, higher trait anxiety was also responsible for determining initial threat evaluation, being responsible for a lower overall threshold for what constitutes threat at initial evaluation. Even low-valence stimuli may be evaluated as threatening in individuals who were more anxious. Thus, higher anxiety from this perspective was more a result of subjective stimulus evaluation, partially independent of the influence of anxious states, causing current goals to be discarded and resources switched to the threat source. From this perspective, a strong enough threat would capture attention regardless of individual differences in anxiety, but higher anxiety would be associated with threat biases when stimuli held less apparent threat value. Supporting this view, in another version of the probe task described above in this section, Wilson and MacLeod (2003) demonstrated that faster detection occurred for items at threat probe locations and slower detection at neutral locations, but that this occurred at moderate levels of threat for highly anxious participants, and only at high levels of threat for participants with lower levels of anxiety. MacLeod et al. (1986) found that full colour threatening scenes were more quickly responded to than neutral scenes, regardless of anxiety level. However, when salience was reduced by making images smaller and presenting them in black and white, less anxious participants became slower to respond and highly anxious participants became faster. The authors therefore suggested that highly anxious individuals have a lower threshold for threat which impacts on the extent to which information deemed threatening is given priority in attention.

Early evidence therefore established a processing bias for threatening information in anxiety, as well as the subjective nature of threat. It was also useful in illustrating the effects of anxiety upon a limited-capacity attentional resource and providing an explanation for the effects of anxious states and dispositions on cognition. While differing in the source of attentional bias (differences in resource allocation toward/away from threat vs differences in threat threshold), these models were primarily focused on the allocation of attention to external stimuli, providing a limited account of how top-down processes affect cognition with higher anxiety. It is however apparent that attention to threat arising from anxiety extends to internal threat representations, with implications for top-down cognitive control. In tasks assessing memory for neutral stimuli, it would be reasonable to assume that there is still a degree of emotional processing ongoing in working memory, with worry occupying resources that are required for processing the stimuli efficiently and effectively. Mathews and Mackintosh (1998) took the view that information is processed in parallel and in competition for limited attentional resources, and that attentional biases only manifest when stimuli are in competition. As with the models outlined above, attentional selection in this context was assumed to be driven by a bottom-up threat detection system that assigns threat value to external stimuli. Higher trait and state anxiety would then be responsible for increased attentional capture by a stimulus considered threatening. As with Mogg and Bradley’s (1998) view, differences in attentional capture or selection between individuals who are more anxious and those who are less anxious would only be observed when the source was mildly threatening, or ambiguous. Their theory however provided a greater role for top-down cognition, suggesting that greater effort could be expended on a given task to reduce attentional bias towards the threat source and toward other, non-threatening target stimuli. The balance struck between the influence of each attentional system would then influence the extent to which cognitive biases occur. Thus, this theory signals the influence of a distinct cognitive control dimension responsible for attention in anxiety.

2.3.4 Anxiety, cognitive control and the role of motivation – Processing Efficiency Theory

Two key theories that have focused more specifically on the relationship between anxiety and the multicomponent working memory model are Processing Efficiency Theory (Eysenck & Calvo, 1992) and its extension, Attentional Control Theory (ACT; Eysenck et al., 2007). Indeed, Baddeley (2007; 2013) has argued that this particular line of explanation accounts well for effects of anxiety on the multicomponent model. Here, it is useful to detail the key assumptions within Processing Efficiency Theory, prior to describing the more precise assumptions of ACT (Section 2.4). These theories, particularly ACT, are central to understanding the rationale for the empirical research reported in Chapters 4-7 of this thesis.

Processing Efficiency Theory (Eysenck & Calvo, 1992) followed the initial view (see Section 2.3.3) that anxious states, predicted by levels of trait anxiety and responses to stressors, can determine individual differences in cognitive performance. However, the theory went further in proposing a specific role of the cognitive facets of anxiety in determining individual differences in task performance. Worry, as a key cognitive component of anxiety, was thought to occupy available executive resources, impacting on the performance of tasks that place notable demands on a limited capacity working memory system. That is, high levels of cognitive anxiety were more likely to incur a performance cost in tasks involving high attentional or working memory demands, with worry reducing the remaining available working memory resources required for task performance. In line with earlier evidence (see Section 2.3.3), the view was that the efficiency (i.e. the ratio of performance effectiveness to effort expended), with which a given task could be performed may be impaired due to excessive worry under threat. This is the case more so than for effectiveness itself (i.e. performance quality such as overall accuracy). The theory also included the assumption that anxious states, more so than trait anxiety, impact cognition. As such, the theory was primarily focused on performance deficits arising from specific situations.

Importantly, it was also argued that efficiency may be upheld providing that additional effort is expended towards the task, suggesting that motivation plays a role in determining the extent to which performance is affected by anxiety. Eysenck (1985) provided initial evidence of monetary incentives improving performance of a letter transformation task in low-anxious individuals, but not high-anxious individuals. By comparison, studies of anxiety and performance incentives in adolescents suggest that performance in high anxious individuals may be improved by monetary incentives (Hardin et al., 2009), but to a lesser extent than for low anxious individuals (Hardin et al., 2007; Jazbec et al., 2005).

There is also evidence that high-anxious individuals will be less motivated to use compensatory strategies when tasks require minimal effort or goals are unclear. Hayes et al. (2009) showed that anxiety negatively impacted performance of a category learning task when learning was incidental and effortless, but no such effect occurred when learning required intent and, in turn, greater effort. More recently, Hoshino and Tanno (2017) informed naive participants that a continuous processing span task was a reliable measure of their IQ, and they were asked to try as hard as possible to achieve the best possible result. The authors interpreted this as a highly motivating instruction. Their results demonstrated that high trait anxiety was associated with less successful working memory maintenance as task demands increased, but only in the low-motivational condition. In the highly motivating condition, anxious participants showed a greater variability in pupillary responses, which the authors interpreted as participants investing more effort into the task. However, what constitutes motivation using these instructions is difficult to parse. Edwards et al. (2017) similarly informed participants that their task was a measure of IQ, and then deceptively informed participants that they were performing below expected levels between practice and test blocks. This manipulation was interpreted as inducing situational stress (i.e., the manipulation was a situation-specific stressor), and was associated with deficits in performance for higher self-reported levels of cognitive trait anxiety.

Processing Efficiency Theory therefore developed on previous literature regarding the effects of anxiety on cognitive performance in the presence of threat. The theory was based on consideration of the impacts of task difficulty and associated motivations on highly anxious individuals' performance. Furthermore, Eysenck and Calvo (1992) specifically suggested that anxiety impacts on cognitive processing via executive resources. There was, however, limited focus on individual differences in trait anxiety independent of stressors, and little consideration for the specific executive control processes that may be affected by anxiety. Ultimately, the theory raised further issues for clarification that have continued to be pertinent in the working memory literature. First, to what extent do task demands, above and beyond those that limit cognitive resources, modulate negative effects of anxiety? Second, do cognitive strategy and effort mitigate performance deficits arising from anxiety?

2.4 Attentional Control Theory

Attentional Control Theory (Eysenck et al., 2007) expanded on the Processing Efficiency Theory, including specific assumptions about the impact of anxiety on the functions of the central executive component of working memory (see Section 1.3.3). The key assumptions included in Attentional Control Theory, and described throughout the following subsections, can be summarised as follows:

1. Anxiety impacts on lower-level executive functions (see Section 2.4.1)
2. Anxiety increases the influence of a stimulus-driven attentional system at the expense of a goal-directed attentional system (see Section 2.4.2)
3. Anxiety affects performance efficiency to a greater extent than performance effectiveness (see Section 2.4.3)
4. Anxiety impacts attention differently, depending on the level of motivation or effortful processing required (see above Section 2.3.4)

While there is inevitable overlap in the implications of each assumption for the effect of anxiety on cognition, the first three assumptions are each considered in turn, in order to provide an overview of the current understanding of the impact of anxiety on attention and subsequent cognitive performance. Sections 2.4.1 and 2.4.2 will primarily cover behavioural evidence, with the particular relevance of neural and physiological outcomes to performance efficiency outcomes discussed in Section 2.4.3.

2.4.1 Anxiety impacts lower-level executive functions

According to ACT, high levels of subclinical anxiety impact negatively on the effective and efficient executive control of attention. Eysenck et al. (2007) drew specifically on three key central executive functions identified by Miyake et al., (2000; see also Miyake & Friedman, 2017), that is, the abilities to shift between tasks, control interference from irrelevant information, inhibit prepotent responses, and update the contents of memory. Thus far, evidence has more consistently shown deficits in inhibition and shifting, with less reliable effects on memory updating (see Shi et al., 2019 for a meta-analysis; see also Berggren & Derakshan, 2013; Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011, for reviews). This pattern of results is consistent with Eysenck et al.'s (2007) argument that the updating function represents brief, passive memory storage rather than the direct control of attention and is therefore less likely to be affected by anxiety. A brief overview of previously observed effects of anxiety on each executive function is provided below.

Inhibition. Effects of anxiety on inhibition have been observed across a range of experimental paradigms. There is considerable evidence for reduced efficiency of these attentional functions, arising from attentional biases to threat in high anxiety, as shown in tasks such as the emotional Stroop (see also Section 2.3.3). Bar-Haim et al.

(2007) reviewed reliable effects of anxiety on performance of this task wherein an inability to inhibit distraction from negatively valanced, but not neutral, words or faces results in increased delays in completing the task (i.e., naming the colour in the Stroop task). Delayed disengagement from threat and faster engagement with threat have also been shown across visual search and spatial cuing tasks, respectively (see Cisler & Koster, 2010, for a review).

Importantly, however, negative effects of self-reported trait anxiety on inhibition have been observed in contexts independent of threat, such as in antisaccade tasks with neutral cues (Ansari & Derakshan, 2010; Ansari & Derakshan, 2011a; Derakshan et al., 2009a). Increased saccade latencies away from salient nontargets towards targets at higher levels of anxiety, but no increased latencies towards targets in the absence of distractors, indicated a specific difficulty to inhibit the influence of the distractor. Reduced inhibitory efficiency has also been observed in a clinically diagnosed group of anxious adolescents (Jazbec et al., 2005; see also discussion of Garner et al., 2009, in Section 2.4.3). Regarding inhibition in Stroop tasks, Berggren and Derakshan (2014) found that participants reporting high levels of trait anxiety made slower responses in response incongruent, but not congruent, conditions in which the words used were neutral.

Reduced inhibition in the absence of threat extends to visual search tasks. It has been demonstrated that a group reporting high trait anxiety was significantly slower to respond in a visual search task compared to a group reporting low trait anxiety when an irrelevant distractor was presented during the task (Moser et al., 2012). Furthermore, effects of distractors on performance, specifically in high trait anxiety, have been exacerbated as task-relevant perceptual load (i.e., the number of items that must be searched) is increased (Sadeh & Bredemeier, 2011). Thus, there would appear to be a specific difficulty in inhibiting attentional capture from irrelevant stimuli at high levels of anxiety, regardless of whether the irrelevant stimuli are threatening.

Further evidence for reduced inhibition applies to the inhibition of prepotent responses. Evidence from the Go/No-Go paradigm has indicated that highly anxious participants were less efficient (i.e. slower) in responding during trials where it was correct to respond (Go trials), but this did not extend to how effectively they performed (i.e. no fewer correct Go trial responses or incorrect No-Go responses; Pacheco-Unguetti et al., 2012; Wong et al., 2013; although see discussion of Edwards et al., 2017 in Section 2.4.3).

Shifting. Though studied to a lesser extent, the effects of anxiety on shifting ability have proven reliable thus far. Evidence has come from studies employing the Wisconsin Card Sorting Test (Grant & Berg, 1948), wherein participants are required to sort cards according to specific criteria which intermittently vary. Inefficient shifting is indicated by the continued use of previous sorting criteria that no longer apply (perseverative errors). Here, a greater number of perseverative errors has been associated with higher self-reported trait anxiety (Caselli et al., 2004). A greater number of errors and greater overall task completion time has also been associated with higher state anxiety (Goodwin & Sher, 1992). Elsewhere, anxiety has been associated with slower performance in a task-switching paradigm compared to performance in a single task, with the effect being exacerbated as task complexity increased (Derakshan et al., 2009b). In a version of a mixed saccade paradigm, Ansari et al. (2008) found that participants self-reporting high levels of trait anxiety did not show the same reduction in saccade latencies when switching between pro- and anti-saccades that less anxious participants did. Thus anxiety may not only reduce shifting efficiency, but also impede potential benefits.

Updating. It is important to clarify how the concept of updating is defined in both the anxiety and working memory literature. In the anxiety literature, updating reflect the monitoring of newly encountered information and the maintenance of previous information in working memory as a function of the central executive (e.g., Berggren & Derakshan 2013; Shi et al., 2019). This also applies to the working memory literature, however updating can also be interpreted as a product of both attentional mechanisms and other mechanisms specified in recent multicomponent models of working memory (e.g., Baddeley, 2012, Logie, 2011; Hitch et al., 2020), rather than a purely attentional function. Given the limited research considering the effects of anxiety on working memory in the context of multicomponent models, it is difficult to highlight a specific mechanism that is responsible for updating. Indeed, researchers have previously assumed that anxiety has less effect on the updating of working memory than the inhibition and shifting functions of memory (Eysenck, 2007; Berggren & Derakshan, 2013). At least conceptually, the product of updating information in working memory is reflected in the episodic buffer/focus of attention component of working memory proposed by Hitch et al. (2020; see Figure 1.5). In Hitch et al.'s model, the episodic buffer function is responsible for interfacing with the sensory-specific stores and the central executive, and the focus of attention being where the integrated information from these stores is held for direct access. To further clarify the attention/working memory distinction, where inhibition and shifting may primarily reflect the processes involved in the direction of attention to or from internal or external information, updating extends to a subsequent or underlying stage of processing: active maintenance of information with access to conscious awareness as it is held within short-term storage. With this in mind, the present discussion of updating here will be limited to tasks that assess the ability to maintain information 'online' temporarily, rather than assess the ability to filter information from working memory or the capacity of working memory (see Section 2.5).

The tasks that have primarily been used to assess updating with respect to anxiety are the reading span task and *n*-back task, both of which are considered complex span tasks – i.e. they measure both storage and processing capacities of working memory as opposed to storage alone (Unsworth & Engle, 2006). Daneman & Carpenter's (1980) reading span task requires participants to read a series of sentences and make judgements on their content (e.g. true/false) whilst also remembering the final word in each sentence, before being asked to recall the words following presentation of a set number of sentences. Effects of anxiety on reading span performance have been mixed, leading to the more reserved assumptions made by Eysenck et al. (2007) as to the effect of anxiety on memory updating. Reading span performance appears to be impaired in highly anxious individuals under stressful compared to non-stressful conditions (e.g. Darke, 1988; Calvo et al., 1992). However, this does not necessarily equate to worse performance in highly anxious individuals overall. For example, Sorg and Whitney (1992) found that highly anxious individuals performed better than less anxious individuals in non-stressful conditions, but were the only group to see a drop in performance under stress. Meanwhile, in reading span tasks without a stressful condition, effects of anxiety on performance have failed to emerge (e.g. Calvo, 1996). Thus, a prevailing view has previously been that anxiety may affect updating, but only under stressful conditions (Eysenck et al., 2007). Certainly, other motivational factors do appear to influence reading span performance at higher levels of anxiety. Edwards et al. (2016) found that higher trait anxiety predicted better reading span efficiency when participants also reported being more committed towards the goals of the task.

As an alternative measure of working memory updating, the *n*-back task (Kirchner, 1958) asks participants to process a sequence of information (for example letters or images) and determine whether the most recently encountered stimulus is the same as one presented *n* items previously. The *n*-back may be considered a dynamic complex span task as information must be maintained while new information is processed (Moran, 2016). In a meta-analysis, Moran did in fact find that performance dynamic span tasks such as the *n*-back – alongside performance in simple span and other complex span tasks - are affected by anxiety, with higher anxiety generally related to poorer performance. It is useful, though, to refer to some specific findings to highlight the complexity of the association between working memory updating and anxiety. Verbal *n*-back performance appears to be negatively associated with higher levels of experimentally induced anxiety, but only at low-moderate levels of task difficulty (Vytal et al., 2012; Vytal et al., 2013). By comparison, visual *n*-back performance appears to be disrupted by induced anxiety regardless of task difficulty (Vytal et al., 2013; Shackman et al., 2006). As with reading span performance, effects of anxiety have appeared to manifest specifically when anxiety is induced (i.e. the situation is stressful), with other studies employing the *n*-back failing to show an association between trait anxiety and performance (Patel et al., 2017). Despite this, there is evidence that particular components of trait anxiety may affect updating, specifically the worry component (Gustavson & Miyake, 2016). Thus, it is necessary to further assess the effects of anxiety on working memory with regard to updating as well as capacity, and also to further assess the relationship between top-down/bottom-up processing and working memory.

2.4.2 Anxiety is associated with an imbalance between top-down and bottom-up attention

The impacts of anxiety on attention described in Section 2.4.1 primarily reflect top-down executive control processes. However, it is suggested that reduced attentional control capabilities associated with anxiety occur due to an imbalance between top-down and bottom-up attention. With ACT, Eysenck et al. (2007) adopted the assumption of interactive attentional systems proposed by Corbetta and Shulman (2002; see Section 1.4), suggesting that volitional attentional control is reduced as automatic capture of attention by behaviourally relevant external stimuli is increased. Expanding further, however, Eysenck et al. proposed that attentional systems are not optimised to attend to behaviourally relevant stimuli at high levels of anxiety, but instead threatening and irrelevant stimuli. Thus, unless a given task specifically involves threatening stimuli, the focus paid to the task is reduced (see Section 2.3.4 regarding motivation to perform in cognitive tasks). Therefore, it should be possible to observe performance deficits in cognitive tasks where there is an absence of threat.

Although ACT involves assumptions specifically about the inhibition, shifting and updating functions of attention, other studies have directly tested the effects of anxiety on bottom-up attention, alongside executive attention. In particular, there is a range of studies that have examined effects of anxiety on performance of the

Attentional Network Test – Interactions (ANT/ANT-I; Callejas et al., 2005). This task specifically assesses the attentional networks described by Posner (e.g., Posner & Petersen, 1990; Posner & Rothbart, 2007, see Section 1.3.5), combining a spatial cuing procedure and flanker task. In the ANT-I, participants are presented with a fixation point, followed by an auditory alerting tone in half of trials, intended to signal that a target stimulus is about to appear. An orienting cue is then presented at either above or below the fixation, or not at all, in a third of trials. Finally, a target arrow cue is presented at either location, flanked by either congruent (same direction) or incongruent (opposite direction) arrows. Participants are then asked to indicate the direction the target arrow is facing. The paradigm allows researchers to test whether perceptual alerting and orienting cues facilitate performance, either individually or in interaction with one another in the 'interactions' version of the task. The paradigm also tests whether individuals can exercise executive control to manage response conflict due to incongruency (again either individually, or by interacting with the perceptually-driven attentional factors in the 'interactions' version of the task).

Although studies using the ANT/ANT-I have generally found associations between anxiety and the attentional networks, these effects have been inconsistent, potentially reflecting the unique attentional modulation associated with different domains of anxiety and specific version of the ANT employed. Pacheco-Unguetti et al. for example, have found that reduced executive control is associated with both trait anxiety (Pacheco-Unguetti et al., 2010) and diagnosed anxiety disorders (Pacheco-Unguetti et al., 2011). However, higher state anxiety was associated with increased attentional alerting and orienting (Pachecho-Unguetti et al., 2010). One explanation for this discrepancy is that state anxiety is transient and reflects temporary increased arousal of the attentional networks, while trait anxiety is more stable and associated with reduced prefrontal activation (see for example discussion of Bishop, 2009, in Section 2.4.3). These results were however inconsistent with those from other studies which investigated the impact of trait social anxiety on the attentional networks. In these studies, anxiety was associated with reduced activation of the orienting network (Heeren et al., 2015; Moriya & Tanno, 2009). This discrepancy would appear to be based on the specific timings of the task procedure, which varied between tasks. As noted by Moriya (2018), those studies in which positive associations between anxiety and orienting were found used shorter intervals between the orienting cue and flanker task than those in which negative associations were found (50 ms vs over 300 ms). As such, orienting would occur involuntarily in the shorter condition, with the facilitation this affords nullified by the need for the voluntary control of attention in the longer condition. Longer intervals between cue and target presentation have been shown to correspond to an increase in Contingent Negative Variation activity – an indicator of effort expended towards a task – in high but not low trait anxiety (Ansari & Derakshan, 2011b). This suggests that more effort is required to maintain performance under these conditions, which may not have been enough to uphold performance in the longer ANT intervals. This explanation is further supported by Moriya (2018), who similarly found positive associations between trait social anxiety and the alerting and orienting networks when using a delay of 100 ms between the orienting cue and flanker task.

Thus, anxiety would appear to be associated with facilitated bottom-up attentional processes and impaired voluntary control of attention. This effect appears relatively consistent across paradigms. For example, in visual search tasks (see Sections 2.4.1 & 3.3.1) anxiety appears to be associated with reduced performance efficiency in the presence of additional irrelevant stimuli (Moser et al., 2012), an effect exacerbated by increased task-relevant perceptual load (Sadeh & Bredemeier, 2011). Berggren et al. (2015) also used a visual search paradigm and found that trait anxiety was positively associated with the detection of additional stimuli outside of the search array. Thus, it would appear that anxiety is associated not only with a reduction in inhibition, but also an increase in visual detection. As demonstrated in Figure 1.5, it is currently understood that executive and perceptual attention influence the content of visual working memory. Therefore, it would be expected that anxiety has an impact on visual working memory performance and capacity through executive and perceptual attention (see Section 2.5).

2.4.3 Anxiety affects performance efficiency more than performance effectiveness

Reduced efficiency in attentional control has received more consistent support than reduced effectiveness (Derakshan & Eysenck, 2009; Shi et al., 2019). Typically, efficiency may be defined as task response or reaction times (although efficiency measures relating to response times vary; see below) while effectiveness is defined as task performance accuracy. Examples of contexts in which impaired performance efficiency has been observed in behavioural outcomes are in slower task response times (e.g. Derakshan et al., 2009b; Goodwin & Sher, 1992; Moser et al., 2012; Pacheco-Unguetti et al., 2012; Sadeh & Bredemier, 2011; Wong et al., 2013) and greater saccade latencies (Ansari et al., 2008; Ansari & Derakshan, 2010, 2011; Derakshan et al., 2009a). Other studies have measured efficiency as the ratio of accuracy to response times. This better operationalizes efficiency as an outcome that is related to performance effectiveness, without the potential confound of speed-accuracy trade-offs. Here, anxiety has again been associated with reduced efficiency in tasks requiring attentional shifting (Edwards et al., 2015) and inhibition (Edwards et al., 2017).

Other means by which anxiety has been shown to differentially impact performance efficiency and effectiveness is via neuroimaging and physiological measures. Bishop (2009) provided both behavioural and imaging data implicating anxiety in reducing letter search efficiency. In this task, participants were asked to identify whether a target letter (X or N) was present in a low-load letter string (all target letters) or high load string (all different letters). Simultaneously, either a congruent (target letter from string) incongruent (the other target letter) or control (a neutral letter) distractor was presented just below the string. Here, high trait anxiety was associated with slower target identification in the low-load condition, specifically when the incongruent distractor was presented. That is, highly anxious participants showed reduced inhibition of salient distractors, impairing performance efficiency but not performance effectiveness, under conditions requiring less attentional resources, in line with ACT. Moreover, functional magnetic imaging (fMRI) data indicated that the high trait anxiety group showed reduced activation of the dorsolateral prefrontal cortex (DLPFC), an area heavily implicated in executive control, while doing so. DLPFC activity has in fact been shown to increase in a verbal 3-back task (involving verbal processing and short-term storage; Fales et al., 2008) and emotional Stroop task (Basten et al., 2011). These latter two tasks place greater demand on processing than do the conditions in which Bishop (2009) observed changes in activity. This therefore suggests that highly anxious individuals by necessity expend more cognitive effort to keep up with task demands under harder task conditions. An association has also been observed between reduced inhibitory control efficiency and reduced event-related potential activity between cue and target onset in an antisaccade task (Ansari & Derakshan, 2011b). Importantly, across each of these studies, there was no effect of anxiety on how effectively the task in question was performed. Performance deficits appear to be limited to efficiency, the reduction of which is traded off to compensate for the maintenance of equivalent task performance with individuals reporting lower levels of anxiety.

Despite this, there is still some evidence for an effect of anxiety on performance effectiveness. For example, Garner et al. (2009) found that inhibitory effectiveness was reduced in an antisaccade task where other studies had only observed effects of anxiety on efficiency (see Section 2.4.1). Edwards et al. (2017) used a Go/No-Go task, which asks participants to inhibit prepotent button-press responses, and found that both cognitive trait anxiety and experimentally-induced stress were each separately associated with deficits in both inhibitory effectiveness and efficiency. Furthermore, effects of anxiety on both efficiency and effectiveness of cognitive task performance have been observed in recent working memory studies using change detection tasks (e.g. Jaiswal et al., 2018; Spalding et al., 2021). Discussion of the effects of anxiety on visual working memory are the focus of the remainder of this chapter.

2.5 Anxiety and visual working memory

Despite a range of evidence indicating a relationship between anxiety and attention in primarily visual tasks (see Section 2.4), there is comparatively little evidence that explicitly considers the effects of anxiety on visual working memory. Moran (2016), for example, has noted that existing theories of anxiety do not make specific predictions about the potential impacts of anxiety on visual working memory capacity. This is true to an extent. Typically, theories have presumed that anxiety impacts cognition through worry. Worrying thoughts have been suggested to be processed as subvocal speech (Rapee, 1993), requiring the phonological loop (Markham & Darke, 1991). It is argued that because these thoughts are attentionally demanding, they will negatively affect central executive processing (e.g., Eysenck & Calvo, 1992; Eysenck et al., 2007). As such, it is more accurate to say that theories specifically state that anxiety will affect the phonological loop and central executive, assuming no effects on the visuospatial sketchpad component, even if only by omission. This is unusual, given that positive relationships have been observed between working memory capacity and performance in visual tasks requiring attentional inhibition (Unsworth et al., 2004) and the attentional networks (Redick & Engle, 2006).

2.5.1 Anxiety, the central executive, and phonological loop

The view that anxiety only has an effect of phonological and executive processing is supported in a range of previous studies. These have typically used reasoning and span tasks. Anxiety has been shown to reduce digit span performance (Darke, 1988), with effects on reasoning observed in a verbal, but not spatial, task (Markham & Darke, 1991). Negative impacts of trait anxiety have also been observed on verbal and grammatical reasoning, reducing performance efficiency in highly anxious individuals under high, but not low, demand from a secondary task (Eysenck & Derakshan, 1998; MacLeod & Donnellan, 1993).

As noted in Section 2.3.2, a handful of studies have actively compared the effects of anxiety on the different components of working memory. The results of these have largely followed the prediction that effects of anxiety on working memory will manifest primarily in the phonological and executive domains, due to the subvocalization of worry that is characteristic of anxiety (see Section 2.5). One of these studies found that anxiety negatively impacted performance of a visuospatial task (the Corsi task), but only when participants performed a concurrent backwards counting task that reduced available executive resources. Accuracy of the backwards counting task itself was also negatively impacted (Eysenck et al., 2005). Another found that anxiety was specifically associated with a performance decrement in verbal tasks reliant on the central executive, for example letter span and verbal reasoning tasks, but not tasks reflecting verbal or visual working memory capacity, such as word length and pattern recognition tasks (Christopher & MacDonald, 2005). Spatial span and dual task performance (i.e., performance in working memory tasks primarily involving the central executive) have also been negatively associated with worry, (Crowe et al., 2007). However, other results have demonstrated that anxiety may improve working memory performance. Using a similar approach to Christopher and MacDonald, Walkenhorst and Crowe (2009) found that high trait anxiety and high state worry were associated with shorter response times (i.e., improved efficiency) in visual and verbal tasks.

2.5.2 Anxiety and the filtering of distractors from visual working memory

There are an increasing number of studies that have employed measures of performance efficiency and effectiveness to assess the impact of anxiety on visual working memory, with outcomes spanning both behavioural and neural measures. A particular area that has seen researchers address the overlap between visual attention and visual working memory is in assessing how anxiety may affect the filtering of distractors from visual working memory.

As discussed in Section 2.4, participants reporting or experiencing higher levels of anxiety demonstrate greater difficulty inhibiting and disengaging from distractors in visual attention tasks (e.g. Derakshan et al., 2009; Moser et al., 2012). Employing a change detection task, Qi, Ding, et al. (2014) found no difference between high and low trait anxious groups in a measure of items held in and retrieved from working memory (i.e. Pashler's *k*), in addition to response accuracy and response times, even when distractors were presented. However, on the basis of contralateral delay activity (CDA; a neural marker that of which the amplitude increases with increased working memory load, up until working memory capacity is reached), it appeared that high-trait anxious individuals used greater processing resources during the task maintenance phase in distractor conditions of a lower overall perceptual load than in non-distractor conditions. Thus, there may be a specific impact of task-irrelevant information on working memory, with Qi, Ding, et al.'s findings pointing to a specific performance deficit wherein initial inefficient filtering of stimuli at the attentional level has a subsequent effect on working memory maintenance. While this effect was observed for neutral stimuli in Qi, Ding et al.'s study, behavioural deficits have also been observed across threatening and neutral distractors in other studies.

Stout et al. (2013), for example, found that trait anxiety was associated with reduced filtering of threatening stimuli based on CDA amplitudes. Interestingly, Stout et al. (2015) also found that higher scores on a measure of trait anxiety was associated with reduced filtering of threatening and neutral distractors based on Pashler's *k*, with the worry aspect of anxiety specifically associated with reduced filtering of threatening distractors. Supporting evidence for the distinct effects of different facets of anxiety comes from Berggren (2020), who found no difference between participants' working memory capacity in a change detection task based on self-reported anxiety levels, but did find a reduced ability to filter neutral distractors in a task condition that induced apprehension via threat of an aversive noise. Furthermore, the effect was greatest for highly trait anxious individuals. Thus, trait anxiety appears to be associated with poorer filtering of distractors from working memory at both the behavioural and neural level. This has been demonstrated in terms of a general negative association between trait anxiety and distractor filtering, as well as a specific negative association between worry and the filtering of threatening stimuli.

2.5.3 Anxiety and visual working memory capacity

The evidence discussed in Section 2.5.2 suggests that the effects of anxiety on distractor processing at the attentional level have implications for the processing of distractors in working memory tasks. This would be expected due to the crucial role played by top-down and bottom-up attention processes in maintaining items in visual working memory (see Section 1.4). Recently, studies have also found that anxiety is associated with visual working memory capacity, independent of the filtering of external distraction.

The methodology employed by Luck and Vogel (1997; See Sections 1.3.4 & 3.3.1) to assess working memory for individual features and conjunctions of features has been the primary method used to assess the relationship between anxiety and working memory capacity in recent studies. Qi, Chen, et al. (2014) asked participants classified as either high or low in trait anxiety to make same-different judgements for memory arrays that varied in load (either three or four coloured squares). In half of the trials, the colour of one square would change at test, testing the binding of colour to a specific location within the array. Results showed no behavioural differences between participants, regardless of load (i.e. no difference in Pashler's *k* or percentage of correct responses). However, CDA activity (as mentioned in Section 2.5.2, a reliable measure of working memory capacity) reached asymptote in the lower load condition for the high anxiety group, and in the higher load condition for the low anxiety group. Thus, higher anxiety appeared to impact the efficiency of working memory more readily, but not the effectiveness with which participants made same-different judgements. This follows a key assumption included in ACT (anxiety affects performance effectiveness more so than efficiency), as well as earlier evidence suggesting that anxiety may not impact behavioural effectiveness while still having a significant effect on brain activity (e.g. Ansari & Derakshan, 2011; Basten et al., 2011).

As with distractor filtering, effects of anxiety on working memory capacity appear to extend to behavioural outcomes. Jaiswal et al. (2018) compared participants classified as either high-mindfulness/low-anxiety or low-mindfulness/high-anxiety in an attention network test, colour Stroop task and visual change detection task (all featuring neutral stimuli). They found that the high-anxiety/low-mindfulness group were less sensitive to detecting changes (measured by *d*') and had lower overall working memory capacity (Pashler's *k*), as well as reduced Stroop performance accuracy. Furthermore, the high-anxiety/low-mindfulness group were significantly less accurate in the change detection task. This latter behavioural outcome is interesting given that Qi, Chen, et al. (2014) did not find differences in change detection accuracy between anxiety groups. It could be the case the additional selection criterion (mindfulness level) reflected how participants respond to experiences of anxiety. Highly anxious participants who reported low mindfulness may have been more liable to experiencing a performance effectiveness deficit due to being unable to reduce the influence of worry on attention. However, Jaiswal et al. did not compare all possible group combinations (i.e., high anxiety/high mindfulness, and low anxiety/low mindfulness groups were omitted). As such, further study is required in order to properly assess this possibility.

Other findings have demonstrated the effect of state anxiety on working memory performance. Berggren et al. (2017) found that state anxiety was associated with lower change detection accuracy following a neutral, but not fearful face cue, occurring across memory arrays of both four and eight to-be-remembered items. Further to this, in conditions in which four memory items were accompanied by distractors, high state anxiety was associated with reduced filtering efficiency specifically following a fearful cue. Here, the negative impact of anxiety on performance after a neutral cue may have reflected a general increase in anxious cognitions associated with state anxiety, and the reduced filtering following a fearful cue reflecting an increase in receptivity to additional threatening stimuli brought on by the presence of a negative emotional cue. Sari et al. (2017) provided further evidence that induced worry and state anxiety similarly disrupt working memory performance accuracy in the absence of threatening cues.

Anxiety therefore appears to have effects on visual working memory, though these do not always manifest in observable behavioural differences. Further compounding the difficulty in interpreting the effects of anxiety on visual working memory is evidence from studies that suggest anxiety may improve visual working memory capacity. These come particularly from studies of trait social anxiety, i.e., experiences of anxiety that arise specifically from the individual's thoughts that they are being – or will be – evaluated by other people in a social situation that is presently occurring, or may occur in the future (e.g., Schlenker & Leary, 1982).

Evidence from these studies suggests that individuals reporting high trait social anxiety demonstrate greater working memory capacity than low anxious individuals during tasks in which no distractors are present (Moriya & Sugiura, 2012; Moriya, 2018). It is worth restating, as mentioned in Section 2.4.2, that social anxiety has also been associated with better attentional alerting and orienting (see discussion of Posner & Rothbart, 2007, in Section 1.3.5). Meanwhile, trait anxiety has been associated with enhanced detection of additional, to-be-remembered, visual stimuli, regardless of levels of perceptual load (Berggren et al., 2015). It is possible that these disparate outcomes reflect the simultaneous effects of enhanced visual detection and reduced executive capacity in anxiety. High trait anxiety has been associated with a general increase in attentional capture. However, whether this results in improved or impaired task performance may depend upon tasks manipulations and outcome measures. For example, if participants are required to ignore information, this information may not be filtered effectively, disrupting later recall for those reporting high anxiety, as it must be inhibited in favour of task-relevant information. By comparison, if the information in a stimulus set is entirely to-be-remembered, high anxiety may be associated with improved overall recall as there are no stimuli that need to be actively inhibited or switched away from. That is, anxiety is associated with enhanced sensory processing, which may come at the expense of later stage working memory processing. In line with the arguments included in ACT, anxiety increases bottom-up receptivity at the expense of top-down control, and effects of anxiety on visual working memory may be explained by this mechanism. Certainly, this model would represent a more nuanced approach to understanding the relationship between emotion and cognition, suggesting that negative moods are not only associated with cognitive deficits or biases to threat.

The view that the impact of anxiety on cognition can be accounted for within the multicomponent working memory model by these attentional mechanisms can be further extended, considering recent proposed extensions to the recent visual working memory model (e.g., Hitch et al., 2020) and updates to the initial Processing Efficiency Theory (Eysenck & Calvo, 1992). There have been few attempts to achieve this thus far. There is a need to understand the extent to which the assumptions underlying ACT (Eysenck et al., 2007) regarding executive and perceptual attention map on to observed effects of attention on visual working memory. In doing so, the specific mechanisms by which anxiety impacts performance can be better determined. Assessing the impact of anxiety on visual feature binding presents a novel and theoretically informed means of doing this, and findings from the few studies which have previously done this are discussed in Section 2.5.4.

2.5.4 Anxiety and feature binding - visual or visuospatial?

The studies detailed in Sections 2.5.2 and 2.5.3 included tasks that are typically considered tests of visual working memory. However, each of these tasks requires a change detection judgement that is contingent on the location or orientation of a target. With anxiety having recently been associated with reliable effects on verbal and spatial working memory, but not more purely visual working memory (Moran, 2016), it remains difficult to determine whether the performance deficits (or indeed enhancements) observed with higher levels of anxiety are contingent on the spatial variation of the memory objects. The potential effects of anxiety on specifically visual feature binding remain to be tested extensively.

Two published articles have thus far examined the impact of anxiety, or at least certain aspects of anxiety, on the binding of colour and shape features. The first of these, conducted by Moreno et al. (2015), tested the ability of participants, classified as high or low worriers, to remember arrays of three simultaneously presented coloured shapes. Outcome measures included both accuracy and response times for nonbinding memory (i.e., same-different judgements for trials in which a single feature of the tested object may change) and binding memory (i.e., judgements for trials in which features from two memory objects in the sequence may be recombined). The authors reported a main effect of worry group on response times, with the high worry group performing slower overall. Also, based on *t*-tests comparing binding conditions within each group, memory accuracy was significantly lower in the binding condition than nonbinding condition, specifically in the worry group. However, it is important to highlight that there was no significant interaction between worry group and binding condition. Therefore, differential binding performance by worry group was not a reliable effect, suggesting further examination of the relationship between worry and binding is required.

Following on from Moreno et al. (2015), Spalding et al. (2021) compared individual feature memory with binding memory across two experiments. In the first study, participants were separated into groups self-reporting either low, moderate, or high trait anxiety. Memory was tested for individual shape and colour-shape conjunction memory across sequential and simultaneous presentation conditions. There were no significant effects of trait cognitive or somatic anxiety on either performance effectiveness (i.e., accuracy, as reflected in proportion correct responses) or efficiency (i.e., correct response times – RTs in trials where participants responded correctly). In the second study, however, higher trait somatic anxiety predicted lower binding, but not shape, accuracy. Both trait cognitive and somatic anxiety were associated with increased correct RTs across both memory type conditions. This follows Moreno et al.'s (2015) finding, that anxiety may generally reduce working memory efficiency.

Further evaluation of the methodologies employed by each of these studies can be found in Section 3.3.3. The present summary of these findings serves to indicate that the relationship between anxiety and visual working memory requires further detailed exploration. Recently, change detection tasks testing memory for visual feature bindings have provided a range of evidence that anxiety may in fact negatively impact visual working memory. However, it is clear that the specific effects observed remain inconsistent across studies, including those in which similar paradigms are used. Specific issues that remain to be addressed, such as the way in which anxiety is measured, or experimental manipulations that may be employed to explore how anxiety could affect working memory through attention, will be considered in further detail in Chapter 3.

2.6 Chapter summary

Anxiety can be debilitating, with negative implications for daily functioning, even when experiences do not meet the threshold for clinical diagnosis of an anxiety disorder. Given that attention and working memory are vital for every day, moment-to-moment functioning, it is important to establish the extent to which anxiety impacts these processes. Some evidence points to important cognitive functions being less efficient and possibly even less effective with high levels of anxiety, particularly when considering trait anxiety. However, conflicting evidence exists for this theory, with some studies previously indicating that anxiety may improve certain aspects of working memory processing, albeit potentially at the expense of other aspects of performance. Thus, understanding the fundamental underpinnings of anxiety's impact on attention, and subsequently, working memory, is crucial. In Chapter 3, the case will be made for studying the impacts of anxiety on attention and working memory via visual feature binding, taking into account the methodological approaches and limitations of the few studies that have done so thus far.

3 Methodology for investigating the impacts of anxiety on visual working memory

3.1 Chapter overview

Evidence suggests that high levels of anxiety can affect the capacity of visual working memory, and performance in working memory tasks. This can occur even when memory stimuli and distractors are emotionally neutral (see Section 2.5). The impact of anxiety on visual working memory appears to be driven primarily by effects of anxiety on perceptual and executive attention. Despite this, there have been conflicting results as to how reliably anxiety impacts on visual working memory. Some data suggest that anxiety reduces working memory capacity and task performance. However, other studies have not observed significant differences in working memory between participants of varying anxiety levels. Other results suggest that anxiety may even enhance cognition. The aim of this thesis is therefore to better understand how, and via which specific mechanisms, anxiety may impact visual working memory. Recent studies of feature binding in visual working memory have presented paradigms that probe both perceptual and executive attention, and subsequent working memory capabilities. As such, visual feature binding tasks offer a novel means of achieving the thesis aims. This chapter will focus on describing how binding paradigms have previously been used to assess visual working memory, and will outline the specific binding tasks that were employed in the present research to test effects of anxiety on visual working memory (see Chapters 4-7). Consideration will first be given to how anxiety may be measured via self-report, clarifying how anxiety will be measured throughout these empirical investigations. Then, information will be provided regarding the different means by which the impact of anxiety on visual attention and working memory has previously been studied.

3.2 Measuring anxiety

3.2.1 The State Trait Anxiety Inventory

The primary characteristics of anxiety relevant to the investigations reported in this thesis were those which occur at trait level, and which may impact on executive resources (i.e. primarily cognitive symptoms). As such, it was necessary to identify a measure of anxiety which allowed for trait anxiety to be separated from state experiences of anxiety, as well as the cognitive dimension from the physiological dimension.

Spielberger et al. (1970) developed the State-Trait Anxiety Inventory (STAI; revised by Spielberger, 1983) in order to delineate experiences of anxious states from the more enduring dispositional likelihood to experience anxiety. In the STAI State subscale, participants respond to items based on how they feel “right now, that is, at this very moment”, and in the STAI Trait, they indicate how they “generally feel”. There are 40 items in total – 20 per subscale - with reverse-scored items for each dimension. State examples include “I feel at ease” and “I feel upset”, trait examples include “I am a steady person” and “I lack self-confidence”. In the case of the state anxiety scale, 4-point Likert responses indicate the severity of the experience of the given item (“not at all”, “somewhat”, “moderately so”, “very much so”), and in the trait scale, responses correspond to frequency (“almost never”, “sometimes”, “often”, “almost always”). The STAI has proven popular in measuring anxiety in psychological research, demonstrating good internal consistency and test-retest reliability, as well as convergent validity with other anxiety measures (see Elwood et al., 2012; Julian, 2011, for reviews). As such, it has been the most commonly used measure of anxiety in psychological research (Elwood et al., 2012) which, along with the provision of normative data, made it an appealing option for use in the studies reported in this thesis.

However, the STAI has been found to be lacking in discriminant validity, failing to adequately distinguish anxiety from more general negative affect or depression (Balsamo et al., 2013; Bieling et al., 1998). Examining the trait scale of the inventory, Bieling et al. (1998) found support for a hierarchical structure emerging from the STAI, with lower order factors of anxiety and depression underlying a more general factor of negative affect. Balsamo et al. (2013) reached similar conclusions about the trait scale, suggesting that it instead evaluates a general vulnerability to psychiatric disorders, while being correlated with measures of depression to a greater degree than other measures of anxiety, although it was still able to sufficiently discriminate between clinical and nonclinical samples. Meanwhile, Caci et al. (2003) have identified factors relating to anxiety, anhedonia and happiness from confirmatory factor analysis of the STAI. Thus, it would appear that the STAI measures anxiety as well as depression and general wellbeing.

Another disadvantage in the context of the original studies reported in this thesis is further evidence for the STAI's inadequate discrimination of the cognitive and somatic dimensions that are found within both trait and state anxiety (Grös et al., 2007). It was therefore necessary to consider another measure that would allow for a more pure measure of anxiety, and that allows cognitive and somatic symptoms to be separated at both trait and state level.

3.2.2 Trait cognitive vs trait somatic anxiety

The contextual and neurological distinctions between trait and state anxiety have been considered in detail earlier (Section 2.2). While both of these specific manifestations of anxiety have been associated with effects on attention and working memory, the focus of the present studies is on the potential effects of trait anxiety. This is because effects of trait anxiety on attention are specified in Attentional Control Theory (Eysenck et al., 2007), and recent studies of the effects of anxiety on working memory have largely focused on this level of anxiety (e.g. Berggren 2020; Jaiswal et al., 2017; Qi, Chen, et al., 2014; Qi, Ding, et al., 2014; Stout et al., 2013; Stout et al., 2015; Spalding et al., 2021). Trait anxiety by definition reflects a general propensity for anxiety and is therefore more reliable for indicating general anxiety levels as compared with state anxiety.

There is also a need to determine whether effects of anxiety on cognition are determined by the unique dimensions of anxiety. Apprehension/worry and arousal/emotionality are the broad dimensions on which anxiety may be defined at both trait and state level (see Section 2.2.1). Apprehension encompasses cognitive symptoms or responses such as worry or fear, while arousal relates to physiological responses. Within ACT it is assumed that limited executive resources are occupied by cognitive symptoms at high levels of anxiety (Berggren & Derakshan, 2013). Therefore it is of interest to assess the extent to which cognitive and somatic aspects of anxiety may separately impact attention and visual working memory.

Evidence has pointed towards a specific association between cognitive anxiety and attentional control. Edwards et al. (2015) found that, when participants self-reported investing high levels of mental effort in the task, cognitive trait anxiety negatively impacted central executive shifting efficiency in the Wisconsin Card Sorting Test. When participants reported low mental effort, the negative effect of anxiety was more pronounced under situational stress. Extending findings specifically to inhibitory performance in a Go/No-Go task, Edwards et al. (2017) found that trait cognitive anxiety was associated with poorer inhibitory effectiveness at high mental effort and low stress, while efficiency was negatively associated with high anxiety and high stress, specifically when effort was low. In comparison, no associations were found between self-reported trait somatic anxiety, somatic stress, and inhibitory control, highlighting a distinction between the effects of the trait anxiety dimensions.

These findings are in line with others that have looked at the relationship between worry and working memory. Worry is typically considered a key component of anxiety, manifesting primarily in verbal thoughts (e.g., Hirsch & Mathews, 2012; Rapee, 1993; Wells, 1995). As such, worry can be conceived as a predominantly cognitive, rather than somatic, anxious experience. In the studies referred to below, worry has been measured exclusively using the Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990). Psychometric studies of the PSWQ have indicated a clear ability to distinguish diagnosed or diagnosable Generalized anxiety disorder from non-patients, and the measure has been shown to be reliable in both clinical and nonclinical samples (Brown et al., 1992; Meyer et al., 1990; Korte et al., 2016). The measure can be seen to reflect worry at trait level, asking the extent to which "how typical or characteristic" each item is on a 5-point Likert scale (1 – Not at all typical to 5 – Very typical). Trait worry has been associated with less effective updating of working memory; an effect not observed for anxious arousal (Gustavson & Miyake, 2016). Hayes et al. (2008) have also found that, when thinking of a worrying rather than a positive topic, 'high worriers' demonstrated lower working memory capacity as reflected in less random performance in a key pressing task. This effect was not apparent in low worriers. Though effects of cognitive anxiety on memory for neutral information is of particular interest in the context of this thesis, it is also worth highlighting that effects of worry extend to the processing of threatening information. Stout et al. (2015) have found that high worriers are less successful in filtering threatening faces from working memory, again implicating cognitive experiences as the specific factor behind attention/working memory deficits in anxiety.

Inconsistencies do however tend to appear when considering the means by which anxiety is measured. While the above studies involved use the PSWQ to measure the cognitive dimension of anxiety, other studies have varied the means by which worry is measured. Two of these studies have shown that cognitive, but not somatic, anxiety impairs cognitive performance, but have used a measure of test anxiety at state level to indicate levels of worry and emotionality (Beaudoin, 2018; Mella et al., 2018). Where a negative effect of somatic anxiety on cognition has been found, the researchers have separated the Beck Anxiety Inventory (BAI; Beck & Steer, 1993) into two separate scores for cognitive and somatic anxiety (Schoen & Holtzer, 2017). This is despite BAI typically only representing anxiety levels in terms of a single score across anxiety dimensions (Roberts et al., 2016). This measure also differs as it asks participants to indicate their level anxiety over the period of the preceding week, up to and including the time of completing the measure. There is evidently a need to defer to measures that reliably separate dimensions of anxiety in order to better understand the respective roles of cognitive and somatic anxiety – at trait and/or state level – in influencing cognitive processes.

3.2.3 The State-Trait Inventory for Cognitive and Somatic Anxiety

The State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree et al., 2008) is the only available self-report inventory with scales measuring both trait and state anxiety, as well as cognitive and somatic symptoms (Roberts et al., 2016). Ree et al. (2008) have highlighted the specific reasons for the development of this measure. First, there is value for researchers and clinicians in being able to discriminate cognitive and somatic dimensions of anxiety. While individuals may self-report similar levels of overall anxiety, the specific profile of their anxious experiences may vary drastically. For example, one individual may report a greater degree of somatic anxiety, but low cognitive anxiety, while another individual may report the opposite pattern, or indeed similar levels of each type of anxiety. Global measures of anxiety (e.g., the STAI; Spielberger et al., 1970; Spielberger, 1983) do not capture these profiles.

Furthermore, while some measures have previously measured both cognitive and somatic symptoms, Ree et al. (2008) note issues with their applicability to measuring anxiety in trait or state terms. For example, the Cognitive Somatic Anxiety Questionnaire (Schwarz et al., 1978) measures a tendency to experience anxiety, but does not correspond clearly to definitions of either trait or state anxiety. The Endler Multidimensional Anxiety Scales (Endler et al., 1991) and the Lehrer and Woolfolk Anxiety Questionnaire (Lehrer & Woolfolk, 1982) have meanwhile only made the cognitive-somatic distinction in one dimension – the former in measuring trait anxiety and the latter in state anxiety. This also applies to measures of performance anxiety in sport, with the widely used Competitive State Anxiety Inventory-2 (CSAI-2; Martens, et al., 1990; CSAI-2R; Cox et al., 2003) failing to account for trait responses. The aforementioned undesirable discriminant validity observed in the STAI (Spielberger et al., 1970; Spielberger, 1983, see Section 3.2.1) represents another reason for the initial development of the STICSA (Ree et al., 2008). A further benefit of the STICSA is that the somatic features of anxiety that it measures may more reliably indicate anxiety-specific somatic arousal, as opposed to somatic symptoms associated with other health conditions. The BAI (Beck & Steer, 1993), for example, has been criticised for including somatic items that may in fact reflect symptoms of other physical health conditions, such as cardiovascular or respiratory disease (Therrien & Hunsley, 2012).

The STICSA (Ree et al., 2008) is administered as two questionnaires, one measuring “general mood”, and the other measuring “mood at this moment”. In the Trait version, participants are asked to indicate how often, in general, each of the 21 items representing the cognitive dimension of anxiety (10 items, e.g. “I think that the worst will happen”) and somatic dimension of anxiety (11 items, e.g. “My heart beats fast”) have applied to them. Participants respond on a 4-point Likert scale (1 - “almost never”, 2 - “occasionally”, 3 - “often”, 4 - “almost always”). In the State version, participants respond to the same items as in the Trait version, and are asked to indicate the extent to which each item applies to them at the time of completing the scale (1 - “not at all, 2 - “a little”, 3 - “moderately”, 4 - “very much so”). Higher total scores indicate higher levels of anxiety (cognitive min-max = 10-40, somatic min-max = 11-44, overall min-max = 21-84). The full STICSA scale can be viewed in Appendix A.

Initial studies have shown the STICSA to have adequate internal consistency in a student sample (Ree et al., 2008), and still higher consistency in individuals with anxiety disorders (Grös et al., 2007; see Table 3.1). Grös et al. (2010) also found that internal consistencies on the trait scale were highly consistent for self-reports from participants (cognitive $\alpha = .92$, somatic $\alpha = .94$) and reports from a friend (both $\alpha = .94$). Although there were only low correlations between self-reports and friend reports on both subscales (all $r < .30$), the authors noted that the STICSA-Trait showed the highest self-other correlations of all anxiety measures assessed. They argued that the low self-other correlations across measures may have been an artifact of the undergraduate university student sample, who may have had shorter and less well-established friendships. The STICSA also has good convergent validity with the commonly used STAI (Trait $r = .66$, State $r = .65$, Grös et al., 2007; Trait $r = .60$, State $r = .65$, Roberts et al., 2016) and measures of social anxiety and post-traumatic stress disorder (Lancaster et al., 2015). It also shows adequate divergent validity from measures of depression, such as the Beck Depression Inventory and depression subscale of the Depression Anxiety Stress Scales (Grös et al., 2007; Ree et al., 2008). While still strongly correlated with measures of depression (Balsamo et al., 2015; Lancaster et al., 2015; Roberts et al., 2016), the STICSA has been shown to be significantly less so than the STAI (Roberts et al., 2016), though more so than one measure of social anxiety (Lancaster et al., 2015). This would suggest that although it may still be difficult to separate anxiety and depression in self-report measures – particularly in light of the comorbidity of anxiety and depressive disorders (see Section 2.3.1) – the STICSA is generally more successful in doing so than the STAI. Similar results regarding the internal consistency, reliability and validity of the STICSA have been observed in a sample of Italian adults (Carlucci et al., 2018) and also with elderly Italian adults (Balsamo et al., 2015), with good internal consistency also found in a preliminary study of a child sample (Deacy et al., 2016). Another advantage of the

STICSA in comparison with the STAI is that it is freely available to use in research settings. It should however be noted that, of the studies referred to above, only Lancaster et al. (2015) found a poor fit to the four-factor structure of the STICSA in their sample. Despite this, they only identified a single item that loaded relatively poorly, on the cognitive subscale at both trait and state level. The authors noted that the homogenous nature of the participant sample (all undergraduate students from a single university population) may have accounted for the unexpected poor fit.

Table 3.1 Internal consistencies observed for STICSA subscales in student and patient samples.

	Trait Cognitive *α*	**Trait Somatic *α***	**State Cognitive *α***	**State Somatic *α***
Undergraduate students (Ree et al., 2008)	.75	.80	.84	.75
Individuals with anxiety disorders (Grös et al., 2007)	.87	.87	.88	.88

Usefully, an attempt has been made to designate cut-off scores for the STICSA-Trait, suitable for distinguishing (non-diagnostically) non-anxious controls from anxiety patients (Van Dam et al., 2013). The optimum for the overall scale is suggested to be 43, with a classification accuracy of .74, although a cut-off score of 40 may be more sensitive, with identified cases of probable anxiety disorder rising from 11.5% to 17.0% when this is applied. It should be noted that this percentage range is in line with previously reported prevalence rates of anxiety disorders (Section 2.2.3), supporting the value of the STICSA as an accurate tool for assessing levels of trait anxiety. Van Dam et al.'s (2013) results also suggested cut-off scores of 23 for the cognitive subscale and 18 for the somatic subscale in determining probable cases of anxiety, providing reference values for potential group comparisons in research. Average trait scores reported by a sample of undergraduate students were 17.10 (*SD* = 7.20) for the cognitive subscale and 16.90 (*SD* = 6.70) for the somatic subscale (Grös et al., 2010). By comparison, scores in a sample of patients with anxiety disorders ranged from an average of 26.60 (*SD* = 7.00) to 29.70 (*SD* = 7.30) for the cognitive subscale and 22.40 (*SD* = 6.50) to 23.70 (*SD* = 7.30) for the somatic subscale, providing further frames of reference in classifying participants.

Given the clear benefits of the STICSA, empirical research using the STICSA as a primary measure of anxiety has steadily increased since its introduction. Most pertinent to the investigations reported in this thesis are a series of studies assessing the impact of anxiety, situational stress, and mental effort on executive functions (Edwards et al., 2015; 2017) and processing efficiency (Edwards et al., 2016). Given the theoretical value in discriminating anxiety from other type of negative affect, and in comparing the relative contribution of cognitive and somatic dimensions to cognitive performance (at both trait and state level), the STICSA was adopted as primary measure of anxiety throughout the present research.

3.3 Experimental methods for investigating the impact of anxiety on visual working memory

3.3.1 Commonly used visual working memory tasks

As highlighted by Moran (2016), no existing theory of anxiety makes specific predictions about the effects of anxiety on visual working memory capacity. However, there have been a range of studies conducted within the visuospatial domain. Change-detection and visual search tasks have often been employed as measures of working memory capacity, and the direction of attention in this context (see Section 2.5). Change detection paradigms involve participants viewing arrays of visual stimuli, before these are removed from their view. Following this, a new visual display is shown, and participants are required to indicate whether a change has occurred in the new array compared with the one originally presented. Schurgin (2018) highlights the utility of change detection paradigms in being amenable to arrays of different sizes (thus measuring the capacity of visual working memory), assessing the ability to detect change for whole arrays, or for individual items within an array (i.e., single probe tasks).

A commonly used version of the change detection task comes from Luck and Vogel (1997). In this task, participants are presented with arrays of items, such as squares of different colours, presented at different locations on the screen. Following presentation of the initial array, and a brief delay where the array is not presented, the entire array is presented again that is either identical or contains a change to the colour of a single square. Participants are then asked to make a judgement as to whether the newly presented array is the same or different as the one that was originally presented. This task has been employed in the study of anxiety by Jaiswal et al. (2018), results from which indicated that a group measuring high in trait anxiety (as measured by the STAI; Spielberger et al., 1970; Spielberger, 1983) and low in mindfulness – i.e., the ability to focus and regulate attention on a present situation to reduce cognitive and emotional distress (Bishop et al., 2004) – performed worse in accuracy, sensitivity and working memory capacity outcomes than a group measuring low in trait anxiety and high in mindfulness. Despite this finding, there is limited evidence of a reliable effect of anxiety on primarily visual tasks, with negative impacts of anxiety typically observed in tasks assessing verbal working memory, or visual tasks with a spatial component (Moran, 2016). Indeed, other tasks adapting the change detection paradigm have found positive associations between working memory capacity and social anxiety (Moriya, 2018; Moriya & Sugiura, 2012). It is worth noting though that when additional distractors were presented in this type of task, anxiety was associated with impaired distractor filtering (Moriya & Sugiura, 2012). Other studies have found evidence that anxiety is associated with reduced working memory capacity and filtering of distractors during working memory maintenance, as indicated by changes in neural markers of working memory, but observed no effects on behavioural outcomes (Qi. Chen, et al., 2014; Qi, Ding, et al., 2014). Thus, change detection appears to be a useful but relatively underemployed method of assessing the impact of anxiety on visual working memory, offering a means of assessing both the role of perceptual load and distractor presentation.

The impact of anxiety on attention has also been assessed via visual search tasks, which were previously employed by Treisman (see Treisman, 1977) in the development of the feature integration theory of attention (Treisman & Gelade, 1980). In these tasks, participants are asked to identify a target within an array that also includes a number of distractors. For example, Treisman et al. (1977; cited in Treisman, 1977) tasked participants with identifying a target colour (pink or brown) within an array of distractor colours (purple), a target letter (O) within an array of distractor letters (N or T), or conjunctions of the target colour and letter within an array of combined distractor colours and letters. They then increased the array size to compare search performance for individual features vs conjunctions, finding that as set size increases, so to do search times for conjunctions, but not individual features. As such, a utility of the paradigm is assessing the ability to identify a target consisting of one or more features in the face of varying perceptual load. With respect to anxiety, use of a modified letter-based version of the task has shown high anxious participants to have poorer reaction time efficiency when perceptual load increases and an additional distractor is presented (Sadeh & Bredemeier, 2011). Another version, presenting additional stimuli outside of the search area in half of the trials, has shown that high anxious individuals were better able to identify the presence of the additional stimuli (Berggren et al., 2015). Similarly, irrelevant distractors have been associated with less efficiency with high anxiety in a visual search task involving colour and shape cues (Moser et al., 2012; see also Moran & Moser, 2015). There is therefore utility for this type of task in assessing the impact of both stimulus set size and distractors on attention in the visual domain.

The impact of anxiety on the individual components of working memory has been assessed using the Corsi Block-Tapping Test (Corsi, 1972). In a typical version of the task, an experimenter taps a series of blocks in a random order, in lengthening sequences of 1 to 9 blocks. The participant is then tasked with repeating the pattern, testing their capacity to remember sequences of visuospatial information. Eysenck et al. (2005) employed a Corsi Task under conditions of varying secondary task load. Concurrent articulatory suppression and backwards counting tasks were intended to engage central executive resources during performance, concurrent tapping of a Z shape intended to engage the visuospatial sketchpad, and concurrent repetition of "A, B, C, D" intended to engage the phonological loop. Via this method, it was found that only central executive demand was associated with reduced Corsi performance in those with high trait anxiety. There are however issues to consider with this approach. As the Corsi is a visuospatial task, it could be argued that the researchers were assessing the role of the three main working memory components on visuospatial working memory only, rather than general working memory capacity. On the other hand, this presents an interesting finding in that it demonstrates a clear impact of anxiety on visuospatial working memory performance through the central executive. Indeed, studies not assessing anxiety have also found the central executive plays a role in performance of the visuospatial Corsi Task (Vecchi & Richardson, 2001; Vandierendonck et al., 2004).

The anti-saccade task (Hallett, 1978) is another means by which the impact of anxiety on visual attention has been assessed. In this task, participants must inhibit involuntary (i.e. reflexive) eye movements towards a non-target side while making a volitional movement towards the opposite side. Evidence from studies employing different version of this task has pointed to reduced efficiency in high-anxious participants (e.g. Derakshan et al., 2009). Manipulations within this type of task again point to the value in assessing anxiety via a means where perceptual and cognitive load can be manipulated, with findings suggesting that additional cognitive load may impair performance across anxiety levels to a similar degree (Basanovic et al., 2018).

It is therefore possible to assess the impact of anxiety on attention and visual working memory via a variety of experimental paradigms, which are able to probe automatic attentional capture and central executive attentional control. As discussed earlier (Section 1.4.1), developments in visual feature binding paradigms have served to further progress the understanding of the role of these aspects of attention in working memory. Despite this, there has been very limited research using feature binding tasks to assess the role of anxiety in visual working memory.

3.3.2 Visual feature binding tasks

Object properties such as shape, colour, orientation and location are initially processed across specialized 'visual' areas of the brain. It therefore follows that neural and cognitive mechanisms are required in order to perceive and distinguish visually encountered objects based on each individual object's own constituent features (see Wheeler & Treisman, 2002). The binding of multiple features into unitary object representations is central to theories of working memory (see Section 1.4.1), with implications for working memory capacity and the influence that attention may have on this process. This process was initially assessed via visual search tasks (see Section 3.3.1), wherein objects consisting of multiple features were found to be found less efficiently than individual features (Treisman et al., 1977; cited in Treisman, 1977). However, this method did not indicate the extent to which the accuracy of binding may be dependent on executive resources. Change detection tasks allowed for this, the first version of which, in the context of contemporary understanding of visual feature binding, was employed by Luck and Vogel (1997; see Section 3.3.1). In their version of the task, participants were required to bind colours with the location in which they were presented in the initial memory array. Accurate detection of a change in the colour of a single item could then be measured. This was a useful task in providing evidence for the suggestion that storage in visual working memory is dependent on capacity for objects rather than individual features. That is, objects are stored as single bound units rather than multiple representations of individual features (Luck & Vogel, 1997; Vogel et al., 2001; see also Gajewski & Brockmole, 2006; Yeh et al., 2005). Wheeler and Treisman (2002) further expanded on this paradigm by comparing memory for individual features with binding memory for colour-shape conjunctions. Their results suggested that successful maintenance of bindings in working memory may require additional attentional resources compared to maintenance of single features. Binding memory was specifically impaired compared to individual feature memory when participants were required to scan a whole array at test, rather than detect change in a single probe. Thus, a role for attentional processes was implicated in binding memory.

Further notable amendments to this methodology came from Allen et al. (2006), who explored the possibility that either cognitive load or the format in which memory items were presented could impact on binding. In their version of the task, performance was compared across four conditions, testing memory for shapes only, colours only, shape or colour, or colour-shape bindings. For the individual feature memory conditions, test items were either a feature from the array or a feature not presented in the array. For binding memory, participants were tested by being presented with one of two colour-shape combinations; a combination of two features that appeared together in the array (i.e. a correct/same test object), or a combination of two features that appeared separately in the array (an incorrect/different test object). A crucial advantage of this approach to assessing binding memory specifically was that change detection performance for individual features and bindings could be tested (either correct identification of change or false report of a change) while binding errors could be classified as potential 'misbinding' of features presented separately in the initial array. This presented further insight into binding mechanisms than the aforementioned methods (Luck & Vogel, 1997; Vogel et al., 2001; Wheeler & Treisman, 2002). Judgements as to whether the memory item had appeared in the initial array were based on the specific combination of features presented, rather than the number of features being tested alone.

To further highlight the value of Allen et al.'s (2006) methodology it is useful to briefly summarise their results. When participants were asked to perform a concurrent backwards counting task (in either ones or threes; thus, varying cognitive load) or to recall digit strings during the simultaneous presentation of stimuli, these tasks resulted in a general visual working memory deficit. That is, performance was reduced overall compared to control conditions across both feature (shape) and binding (coloured shape) memory. However, binding memory was disrupted to a significantly greater extent than that of individual feature memory when stimuli were presented sequentially, one after the other. This suggests a perceptually driven fragility of binding memory over time, akin to a retroactive interference effect (see Sections 1.2.3 & 1.4.1).

In subsequent amendments to the paradigm, binding errors have been probed more specifically by having participants respond via cued recall, presenting them with one feature from an item in the memory sequence, requiring them to identify the feature with which it was initially presented. Via this version of the task, it is possible to clarify whether binding errors occur due to misbinding within the memory sequence – i.e., incorrect pairing of two separately presented features, as in Allen et al.'s (2006) task – or to incorrect binding of the cue feature with a feature not presented in the memory sequence. Other versions of the task have also included a 'colour wheel' response method, wherein participants are asked to specify the specific colour with which they were previously presented, using a continuous gradient, indicative of memory precision (e.g., Bays et al., 2009).

Evidence from studies adopting variations of cued recall and change detection paradigms have directly informed the methodological approach adopted in the empirical investigations reported in the following chapters, generic details of which are reported in Section 3.4. Specifically, the experimental procedures employed by Hu et al. (2016) formed the basis for the methodology used in Chapters 4 and 5 and are described in Section 3.5.1.

3.3.3 Methodological limitations of previous studies investigating anxiety and visual feature binding

There is a small set of published studies that have used change detection tasks and found negative effects of anxiety on cognitive behavioural outcomes (see Section 2.5). It is useful to briefly restate the methodological approaches of these and consider specifically the limitations that future studies should address. The first of these, conducted by Moreno et al. (2015), compared high and low worriers on memory for arrays of three simultaneously presented coloured shapes. Participants were required to indicate whether a coloured shape at test was the same as another which had been presented in the initial array. In the binding condition, participants were presented with another 3-item array in which features had been interchanged between each object in the memory array in the ‘change’ trials, while each had only changed in one feature (either shape or colour) in the non-binding condition. This presents a notable limitation in that, effectively, binding memory was tested across both conditions. That is, as opposed to comparing memory for feature conjunctions against individual features, the relationship between colour and shape was always integral to making responses. The methodology may explain why a negative effect of worry on response times was observed across conditions, as feature association memory was not being compared to individual feature memory. Furthermore, the authors included an additional cognitive load, above what may be expected to stem from anxiety, throughout the task, with participants counting backwards in threes from a 3-digit number in each trial. Therefore, it was not possible to assess whether worry impacts on binding specifically, or whether this occurs in the absence of load. The studies reported in Chapters 4-7 were aimed at addressing these issues.

In the case of Jaiswal et al.’s (2018) task, which followed the initial Luck and Vogel (1997) procedure for assessing shape-location bindings, the authors found effects of anxiety across accuracy, sensitivity, and working memory capacity outcomes, but specifically in participants reporting high trait anxiety and low mindfulness. Furthermore, they did not assess the effects of all combinations of anxiety and mindfulness levels (i.e., there was no comparison with high anxiety/high mindfulness or low anxiety/low mindfulness groups). Thus, it is necessary to extend the understanding of the impact of anxiety on visual working memory to other anxiety domains, particularly the cognitive and somatic dimensions. This is addressed in the investigations reported in the following chapters by the use of the STICSA (Ree et al., 2008) to measure anxiety, allowing for a meaningful separation of anxious experiences that can better highlight the specificity of any effects anxiety may exert on visual working memory.

Spalding et al. (2021) recently made some progress in addressing the above issues. In their first study, they compared memory performance for individual feature memory (shapes) and binding memory (coloured shapes) while also investigating performance in both simultaneous and sequential presentation conditions. Thus, they expanded on the dual-task and memory type conditions employed by Moreno et al. (2015). They also assessed cognitive and somatic dimensions of trait anxiety using the STICSA (Ree et al., 2008), finding different effects of each dimension of anxiety on visual working memory performance in a second study. While developing on the above stated issues, their methodology arguably lacked the explanatory value of more recent binding methods employed by Hu et al. (2014, 2016). This is because their study did not employ cued recall response methods, which have directly informed suggestions for modelling the relationship between visual working memory and attention (e.g. Hitch et al., 2020). This aspect is addressed in Studies 1 and 2 of this thesis (Chapters 4 and 5). It would also be beneficial to develop further on both the methodology used in these studies, and in Spalding et al. (2021), by probing working memory capacity. Previous evidence from other change detection studies, namely that highly anxious participants reach capacity at three memory items while that for less anxious participants is four items (Qi, Chen, et al., 2014; see Section 2.5.3 & Section 6.2). Studies 3 and 4 therefore address the issue of set size/capacity.

3.4 Common methods employed across the present studies

Each study conducted for the purposes of this thesis was approved by the School of Psychological Sciences and Health Ethics Committee at the University of Strathclyde, prior to data collection. Each study was also preregistered with the Open Science Framework. Links to the registrations for each study can be found in the Method section within their respective chapter, and all registrations may be accessed via the Open Science Framework archive for the project: https://osf.io/ktuzy/. Datasets are to be added following publication of the findings in Chapters 4-7.

3.4.1 Participant samples

In each of the present studies, the target sample was young adults (aged approximately 18 to 35 years). Restricting recruitment by age was important given the well-documented instances of declining cognitive performance in healthy aging (Reuter-Lorenz & Lustig, 2005), particularly within the visuospatial domain (e.g., Brown, 2016; Swanson, 2017). The samples for each study were primarily recruited from the undergraduate student population within the School of Psychological Sciences and Health at the University of Strathclyde, social media, and also through opportunity sampling. In each study, participants provided written informed consent prior to taking part.

3.4.2 Analytic approach

The primary outcome variables of interest in each study were response effectiveness (proportion of correct responses), response error rates (Chapters 4 and 5), and response efficiency (Chapters 6 and 7). The latter was operationalized in two ways, firstly as response times in trials in which participants responded correctly (e.g., Spalding et al., 2021). Efficiency was also operationalized as a function of proportion correct responses divided by response times in correct trials, multiplied by 1000 to aid interpretation (e.g., Edwards et al., 2017).

As noted earlier, trait cognitive anxiety was the primary anxiety factor of interest (see Section 3.2.2). However, trait somatic anxiety was also analysed in order to assess the specificity of any observed effects to the trait cognitive dimension. In each case, and in line with study preregistrations, the primary analyses took the form of mixed factorial analyses of variance (ANOVAs), with anxiety treated as a between-subjects factor. Participants were separated into anxiety groups classified as low, moderate, or high anxiety. High levels of anxiety were based on the suggested STICSA subscale cut-off scores for identifying probable cases of clinical anxiety (van Dam et al., 2013). High cognitive anxiety reflected scores > 23 on the cognitive subscale and high somatic anxiety reflected scores > 18 on the somatic subscale. No criteria have previously been provided for separating low and moderate anxiety levels via the STICSA. However, separating anxiety groups according to these three levels may allow for nonlinear effects of anxiety to be observed and is generally more sensitive than simple low vs high comparisons (e.g., see Spalding et al., 2021, Study 1). The low and moderate anxiety groups were determined based on a post-hoc split of remaining participants as close to the median of their scores as possible. Further multilevel analyses were conducted in order to account for potential linear effects of anxiety as a continuous variable. Various exploratory analyses were also conducted on each set of data, the details of which are provided in the relevant data chapters that follow. Each of the above analyses were carried out using SPSS (version 27; IBM Corp., 2020).

ANOVA results were supplemented with Bayes Factors (calculated using JASP version 0.13; JASP Team, 2020), which provide an estimation of the strength of support for either the null or experimental hypotheses. For main effects and interactions, BF_{incl} is reported, which indicates the strength of evidence in support of their inclusion within the model. BF_{10} is reported for follow-up tests, which indicates strength of evidence for an effect being present. For pairwise comparisons specifically, posterior odds are reported, as these are corrected for multiple comparisons in JASP.

Although they are continuous outcomes, Bayes Factors can also be usefully classified according to the strength of evidence for presence of an effect of predictors on the dependent variable. $BF < 1$ indicates greater support for the null hypothesis (i.e., little evidence for the presence of an effect). Regarding the strength of evidence in support of experimental hypotheses, $BF = 1 – 3$ indicates weak or anecdotal evidence, $BF = 3 – 10$ indicates moderate evidence, and $BF > 10$ indicates strong evidence (Lee & Wagenmakers, 2013).

3.4.3 Materials

Anxiety was always measured via the STICSA (Ree et al., 2008), as per the rationale outlined previously (see Section 3.2), while depression and stress were measured as potential covariates via the Depression Anxiety Stress Scales (DASS-21; Lovibond & Lovibond, 1995, see The Depression Anxiety Stress Scales, 21-item version (DASS-21; Lovibond & Lovibond, 1995)). In the DASS-21, participants are asked to indicate the extent to which various statements (e.g., "I felt downhearted and blue" – depression; "I was worried about situations in which I might panic and make a fool of myself" – anxiety; "I found it hard to wind down" – stress) applied to them over the preceding week (0 = Did not apply to me at all, 3 = Applied to me very much, or most of the time). Higher scores, multiplied by two, indicate higher levels of the construct measured by each subscale. The experimental procedure was programmed in E-Prime (Version 2.0; Psychology Software Tools, Inc.). Memory items were coloured shapes measuring approx. 2.6 cm^2 viewed against a white background. The memory items used in each study were drawn from the same pool of 8 colours (black, light blue, dark blue, grey, green, purple, red, yellow) and 8 shapes (arch, arrow, circle, diamond, flag, plus, triangle, and star; see Figure 3.1). These were adapted from previous visual feature binding studies (e.g., Hu et al., 2014; Ueno et al., 2011). Items included in a given trial were chosen from the pool randomly, without replacement. The implausible suffix features used in Study 2 can be viewed in Section 5.3.3 (Figure 5.1).

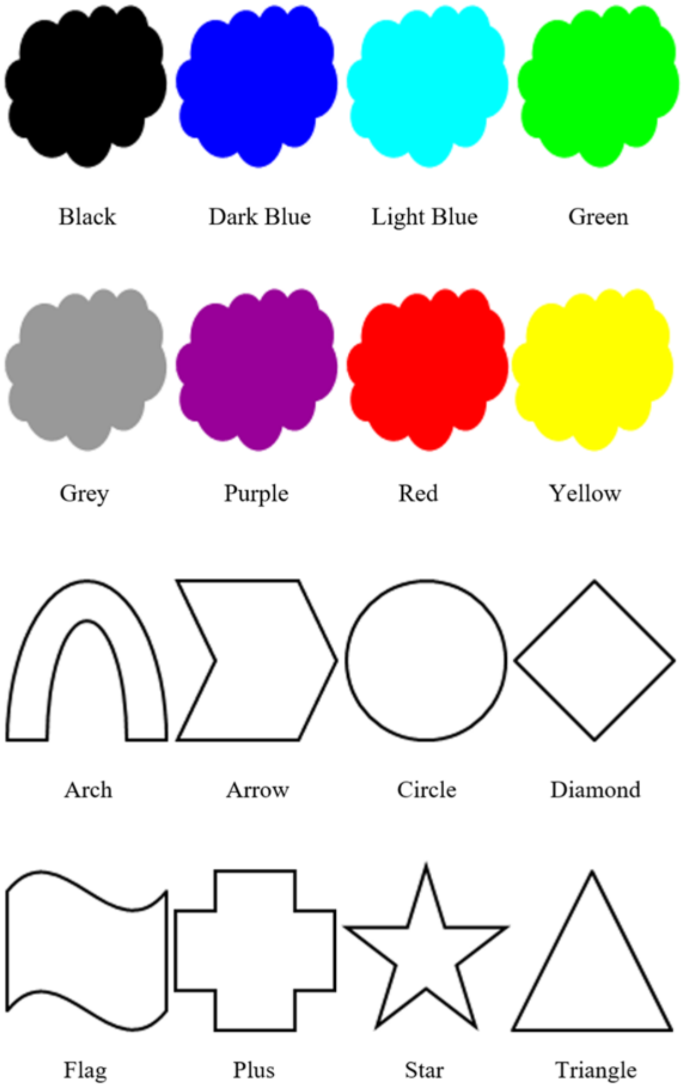

Figure 3.1 The colour and shape features, and their labels, included in the memory pool in Studies 1 to 4.

3.5 Task procedures

3.5.1 Summary of procedures for Studies 1 and 2 (Chapters 4 and 5)

Stimulus presentation and test phases in Studies 1 and 2 (reported in Chapters 4 and 5) adopted the following procedure (adapted from Hu et al., 2016; see Figure 4.1 and

Figure 5.2). Participants were presented with a 500 ms warning cross in the centre of the screen, followed by a 500 ms delay. They were then presented with a 2-digit number for a period of 1000 ms, which they were asked to repeat aloud for the duration of the task, in order to suppress subvocal articulation of the memory array. Following a 250 ms delay, four coloured shapes were presented separately for 250 ms each across a randomly selected corner of an invisible square just above the centre of the screen, with a 250 ms blank screen between each new item being presented. Following presentation of all items and a further 1000 ms delay, the memory feature was presented, and participants were asked to recall aloud the feature that originally accompanied the memory cue. That is, if a colour was presented participants were asked to name the shape it originally appeared with, and vice-versa. Chapter 4 included a further experimental manipulation intended to engage top-down control processes. Specifically, participants were encouraged to direct their attention to specific items in the memory sequence). Chapter 5 included a perceptual manipulation, involving presentation of an irrelevant/to-be-ignored suffix following presentation of the memory sequence. Specific details are provided in the Method sections of each chapter. To minimise the risk of floor and ceiling effects being observed, each study was piloted prior to data collection.

3.5.2 Summary of procedures for Studies 3 and 4 (Chapters 6 and 7)

A change detection response method was employed in Studies 3 and 4 (reported in Chapters 6 and 7), as opposed to cued recall (see Section 6.2 for detailed rationale). The procedures for each study can be viewed in Figure 6.1 and Figure 7.1. Sequential memory arrays were presented in either sets of three or four memory objects. Stimulus presentation rates were unchanged from Studies 1 and 2, however stimuli were presented separately in a row from left-to-right across the screen above the fixation point, as opposed to at the corners of an invisible square in the first two studies. In Study 3, participants were asked to repeat a 2-digit number out loud for the duration of each trial, and were asked to indicate whether a blank shape or coloured shape had been present in (*z* key) or absent from (*m* key) the initial memory array. In Study 4, participants were asked to either repeat a two-digit number out loud, or count backwards in sets of three from a two-digit number, for the duration of the trial. At test, participants made the same keypress responses to indicate whether a coloured shape had appeared in the memory sequence. Further specific details and figures for each task are provided in the Method section of each chapter. To minimise the risk of floor and ceiling effects being observed, as with Studies 1 and 2, each study was piloted prior to data collection.

To underline the procedural approach adopted in the present studies then, visual feature binding paradigms are particularly useful for investigating executive and attentional processes in the context of anxiety (see Section 3.3.2). Across the present studies, it was possible to assess the extent to which strategy instruction (Study 1) and cognitive load (Study 4) affected particularly executive control of attention, while the use of a suffix interference manipulation (Study 2) and comparison of memory for both features and bindings (Study 3) assessed the effect of manipulations at the perceptual level.

3.6 Chapter Summary

The purpose of this chapter was to justify and provide an overview of the methods used in the experimental studies reported in the following chapters. Binding is reliant on executive and perceptual attention processes, at least when information must be processed and maintained as new information is encountered. Executive and perceptual attention are imbalanced at high levels of anxiety, reducing executive resources due to cognitive anxious experiences, and increasing automatic attentional capture. Specific executive factors shown to adversely affect binding are sequential primacy and increased executive demand, factors which interact with one another. At the perceptual level, irrelevant suffixes further interfere with binding in working memory. However, these effects can be mitigated by applying effort to maintain earlier items. Despite the overlap in concepts in the anxiety and binding literature, studies have yet to extensively examine anxiety in the context of visual feature binding. The experimental studies reported in the following chapters sought to assess the specific factors that impact binding in the context of trait cognitive anxiety. This allowed for experimental manipulations that can specifically tap into top-down and bottom-up attention processes. The best identified means of measuring anxiety was the State Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree et al., 2008), as this measure allows for the cognitive and somatic dimensions of anxiety to be considered separately, at both trait and state level. The following chapters will each, in turn, report the rationale, methods, and findings from the four studies completed within the present research programme.

4 Study 1 - Impacts of anxiety on top-down attentional control in visual feature binding

4.1 Chapter overview

This chapter reports the first of four investigations into the effects of anxiety on attention and visual working memory. According to Attentional Control Theory (Eysenck et al., 2007), anxiety impairs cognitive performance by decreasing the influence of the top-down attention system and increasing the influence of the bottom-up system (see Section 2.4.2). To assess this possibility, Study 1 adopted a sequential visual feature binding paradigm in which participants were provided with instructions intended to influence their volitional control of attention towards specific to-be-remembered stimuli (e.g., Hu et al., 2016). Specifically, participants were informed that they would be awarded more points for correct recall of either the first or last item in the memory sequence, depending on the trial block. Participants were grouped according to trait anxiety scores (either relatively low, moderate, or high anxiety). No effects of trait cognitive or trait somatic anxiety were found on recall performance. There were also no effects relating to task instructions. Serial position data were in line with previous research on binding, with a serial position curve demonstrated across conditions. This took the form of the second item in the sequence being less accurately remembered than the first and third items, with the first three items all remembered less accurately than the fourth and final item. Specific implications of these findings for ACT are discussed, particularly regarding a lack of evidence for limitations in top-down attention with higher trait anxiety during visual feature binding. However, potential methodological limitations are also considered, which may further explain this outcome.

4.2 Study 1 – Introduction

4.2.1 Anxiety reduces executive attentional capacity

As discussed in Section 2.4.1, anxiety negatively impacts on an individual's ability to inhibit distraction from irrelevant stimuli (e.g., Moser et al., 2012, Sadeh & Bredemeier, 2011). Anxiety also inhibits an individual's ability to direct their attention away from a non-target stimulus to a target (e.g., Ansari & Derakshan, 2010, 2011a; Derakshan et al., 2009a). This executive dysfunction appears to have implications for the performance of working memory tasks. Eysenck et al. (2005) found that performance of the Corsi blocks task (see Section 3.3.1) was further impaired in highly anxious individuals compared to less anxious individuals when they perform a concurrent backwards counting task, which increases executive load. However, neither a concurrent spatial tapping task nor number repetition task, which engaged spatial and verbal processing, had any effects. Elsewhere, Christopher and MacDonald (2005) found that anxiety patients performed less well than controls in a range of central executive-based verbal working memory tasks, but not a visual task, nor verbal tasks involving phonological similarity or word-length effects. Thus, there would appear to be a general deficit of executive control associated with higher levels of anxiety that has negative implications for visuospatial and verbal working memory tasks.

4.2.2 Sequential binding requires executive attention

As discussed in Section 1.4.1, recent studies of visual feature binding have contributed to the developing understanding of the role of attention in a multicomponent visual working memory. Allen et al. (2006) demonstrated that when features and bindings are presented sequentially, the most recently presented item was remembered best. Moreover, this effect was more pronounced for binding memory as compared to feature memory (see also Brown & Brockmole, 2010; Brown et al., 2017). It would appear that bindings in working memory were particularly fragile to fragmenting, as earlier presented items appeared to be overwritten by those subsequently presented. The recency effect has since been reported consistently across sequential binding studies (Allen et al., 2006; Allen et al., 2014; Hu et al., 2014; 2016). This effect is seemingly due to the final item automatically occupying a privileged state in visual working memory where items are more readily accessible but also more easily overwritten (Hitch et al., 2020). Sequential binding tasks in the first instance are therefore a means of assessing how well participants can maintain items in memory using executive resources in the presence of subsequently presented task-relevant information. As such, sequential binding tasks are an ideal means of assessing whether effects of anxiety on executive control extend to negative effects on visual working memory.

It has also been shown that participants are able to direct their attention towards the first and last items in memory sequences when they are awarded points for recall of those items, resulting in their increased recall (Hu et al., 2014; Hitch et al., 2018). Importantly though, this benefit was consistently offset by reduced recall of non-prioritised items. This meant that performance accuracy levels did not significantly vary between conditions in which different items were prioritised, or a control condition in which all items were valued equally. This suggested that it is possible for individuals to exercise control over their attention to prioritise items in working memory, but that this occurred within the capacity limits of attentional focus (suggested by Hitch et al., 2020, to be close to as little as a single item). The role of the central executive in this process was further supported by evidence from an experiment in which participants were asked to direct their attention towards specific memory items while also completing a concurrent task that increased cognitive load (Hu et al., 2016). Here, the performance trade-offs between prioritised and non-prioritised items were reduced under cognitive load as compared to a control condition. The implication here is that as executive resources are occupied by the concurrent task, the ability to direct attention is reduced, and performance overall is decreased (see also Allen et al. 2006; Allen et al., 2012). To highlight the specific benefit of employing a manipulation of voluntary attentional control within the context of anxiety, this approach would serve to indicate whether anxiety incurs a general cost to executive resources, or specifically in directing attention towards specific information.

4.2.3 Anxiety and sequential binding

Visual feature binding paradigms therefore appear to be ideally suited for further informing the effects of anxiety on attention and visual working memory through, primarily, the central executive. There has been a limited range of studies examining the impact of anxiety on the binding of visual features (see Sections 2.5.3 & 2.5.4). Furthermore, only one of these (Spalding et al., 2021, Study 1) has attempted to address whether anxiety influences performance in a sequential binding task. There was no effect of anxiety observed on either individual feature or binding memory across sequential or simultaneous presentation conditions. Furthermore, there was no effect of anxiety across different serial positions in the sequential condition. This study provided initial evidence that anxiety may not negatively impact binding of visual features, however the task employed varied in key ways from other research examining the role of executive and perceptual attention in sequential binding. First, Spalding et al. used a single-probe recognition response method (change detection judgements via keypress). By comparison, those sequential binding studies that have informed the current understanding of multicomponent visual working memory (e.g. Allen et al., 2014; Hu et al., 2014; 2016) have typically used oral cued recall responses. Although serial position effects have been observed across both cued recall and recognition responses, Allen et al. (2014) have highlighted specific advantages of using cued recall. In cued recall tests, the cue presented is always present in the memory array. By comparison, in recognition tasks, only 50% of trials include a valid cue, meaning that in trials in which the cue was not presented in the array, serial position data cannot be obtained. Thus, there is greater amount of data that can be included in analyses of cued recall responses. Adding to this, Allen et al. note that the performance range is more sensitive. Rather than providing binary yes/no responses, participants are able to provide recall responses based on features presented in the memory array, the broader pool of memory items, or other guessing responses. As such, error data can also be investigated in detail (see Section 3.3.2).

4.2.4 Hypotheses

In Study 1 we adopted the paradigm used by Hu et al. (2016) in order to assess the potential effects of anxiety on visual working memory by targeting top-down attentional control. In their study, participants were asked to complete a visual feature binding task (see Section 3.5.1) and were awarded a varying number of points for the correct recall of either the first or last item in a 4-item sequence. Using this paradigm in the present study, alongside incorporating the comparison of three groups of participants classified as low, moderate, and high in trait cognitive anxiety, we expected to observe a three-way interaction. High trait cognitive anxiety was expected to be associated with reduced recall ability for early sequence items which require more executive resources to maintain, and the effect was expected to be exacerbated with prioritisation instructions as participants reporting lower levels of anxiety saw greater benefit of prioritising items in memory.

4.3 Study 1 – Method

This study was preregistered with the Open Science Framework following commencement of data collection, and prior to data analysis. The pre-registration for this study can be found at https://osf.io/bmvuf, with underlying data to be made available following publication.

4.3.1 Participants

Participants were seventy-two young adults (23 male, 48 female, one preferred not to say) aged 18-38 years (*M* = 23.17, *SD* = 4.92)[1]. Mean years of education was 15.91 (*SD* = 2.67)[2]. Participants were recruited from the undergraduate participant pool for Psychology at the University of Strathclyde, and via opportunity sampling. All participants reported normal/corrected-to-normal vision, and no memory impairments. Accounting for missing data, a final sample size of 68 participants provided complete trait cognitive anxiety questionnaire responses. A retrospective power analysis conducted using MorePower 6.0 (Campbell & Thompson, 2012) indicated this was sufficient to detect a medium-sized effect (n^2_p = .06) for a significant three-way interaction (α = .05, power = .93).

4.3.2 Design

A 3 (trait cognitive anxiety group; low, moderate, high; between groups) x 3 (prioritisation instruction; control, position 1, position 4; repeated measures) x 4 (serial position; 1, 2, 3, 4; repeated measures) mixed factorial design was used. Groups were determined by a split of anxiety scores following completion of data collection, as described in Section 3.4.2 (see Table 4.1 for demographic information within each trait anxiety group). In each case, the high trait anxiety group reflected scores above a recommended cut-off for determining probable cases of clinical anxiety using the STICSA (> 23 for the cognitive subscale and > 18 for the somatic subscale; van Dam

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1 Three participants did not provide their age

2 Three participants did not provide their years of education completed

et al., 2013) and mean scores for that group were within a range of scores previously identified in participants with anxiety disorders, i.e. 26.60 (*SD* = 7.00) to 29.70 (*SD* = 7.30) for the cognitive subscale and 22.40 (*SD* = 6.50) to 23.70 (*SD* = 7.30) for the somatic subscale (Grös et al., 2010). As there has not been cut-off scores provided for differentiating low and moderate levels of anxiety using the STICSA, the remaining scores were split as close to their median as possible. While the cognitive dimension of trait anxiety was of primary interest (see Sections 3.2.2 & 3.4.2), analyses were also run using trait somatic anxiety in order to assess the specificity of any significant outcomes to the different anxiety dimensions (e.g. Edwards et al., 2017; Spalding et al., 2021).

Table 4.1 Participant demographic information by trait anxiety groups for Study 1.

	N	Anxiety Min–Max, *M* (*SD*)	Age *M* (*SD*)	Sex (M:F)	Yrs Education *M* (*SD*)
Trait Cognitive	68				
Low	26	10-18, 15.96 (2.32)	22.88 (4.75)*	7:19*	15.76 (3.72)*
Moderate	23	19-23, 21.09 (1.28)	23.09 (5.50)	6:15#	15.95 (2.15)X
High	20	24-36, 27.75 (3.32)	23.20 (4.90)	8:11*	15.95 (3.15)
Trait Somatic	71				
Low	22	11-14, 13.09 (1.02)	24.14 (6.02)*	5:16*	15.77 (2.43)
Moderate	26	15-18, 16.50 (1.18)	22.19 (4.18)	10:15*	16.04 (2.61)*
High	23	19-34, 23.04 (3.75)	23.17 (4.59)	5:16#	15.91 (3.07)*

NB: values based on **N*-1, #*N*-2, X*N*-3 within each anxiety group due to missing data

The dependent variables were memory accuracy (proportion correct recall of the feature that accompanied the test probe) and proportion of errors. Errors were categorised as either within-sequences confusions (incorrect recall of another feature in the sequence), memory set intrusions (incorrect recall of a feature in the wider memory set), or extra-set intrusions (incorrect recall of a novel feature not present in the memory set). Within-sequence confusions reflect misbinding between items in the memory sequence, while set intrusions are viewed as guessing responses due to loss of the probed binding from memory (Allen et al., 2006).

4.3.3 Procedure

Task materials were as detailed in Section 3.4.3. Participants first completed the Trait and then the State versions of the STICSA (Ree et al., 2008), followed by the DASS (Lovibond & Lovibond, 1995). They then completed the binding memory task. Experimental trials were blocked by prioritisation instruction, with block order counterbalanced across participants. The order of the specific trial list and the task instruction was alternated with each participants, such that there was a total of 36 orders of administration. Although the order was fully counterbalanced across the entire sample, it was not possible to do this within each anxiety group, which were created a posteriori.

In each block, participants completed six practice trials followed by 40 experimental trials. Each of the four serial positions were cued 10 times, over the course of each block. Cue type (colour or shape) was also randomised during trial generation, within the constraint that each type was presented 5 times each per serial position. The order in which each serial position and cue type was presented was randomised, but this randomised order remained the same for each participant. Participants were initially instructed on how to complete the task, then shown the stimuli included in the task and an example of a trial. Prior to each block, they were informed that correct recall would be rewarded with points, depending on the block condition, and that their overall performance would be based on the number of points they scored. In the control condition, participants were informed that each correct response was worth one point, regardless of the serial position of the item that was probed. In the 'prioritise item 1' and 'prioritise item 4' instruction conditions, participants were told that correct recall would be worth four points when the first and last items, respectively, were probed, with correct recall of the other items being worth one point. Participants were also informed that the item being cued was selected at random, and that each item was equally likely to be tested. Specific instructions for each condition can be viewed in Appendix C. An example trial procedure is presented in Figure 4.1.

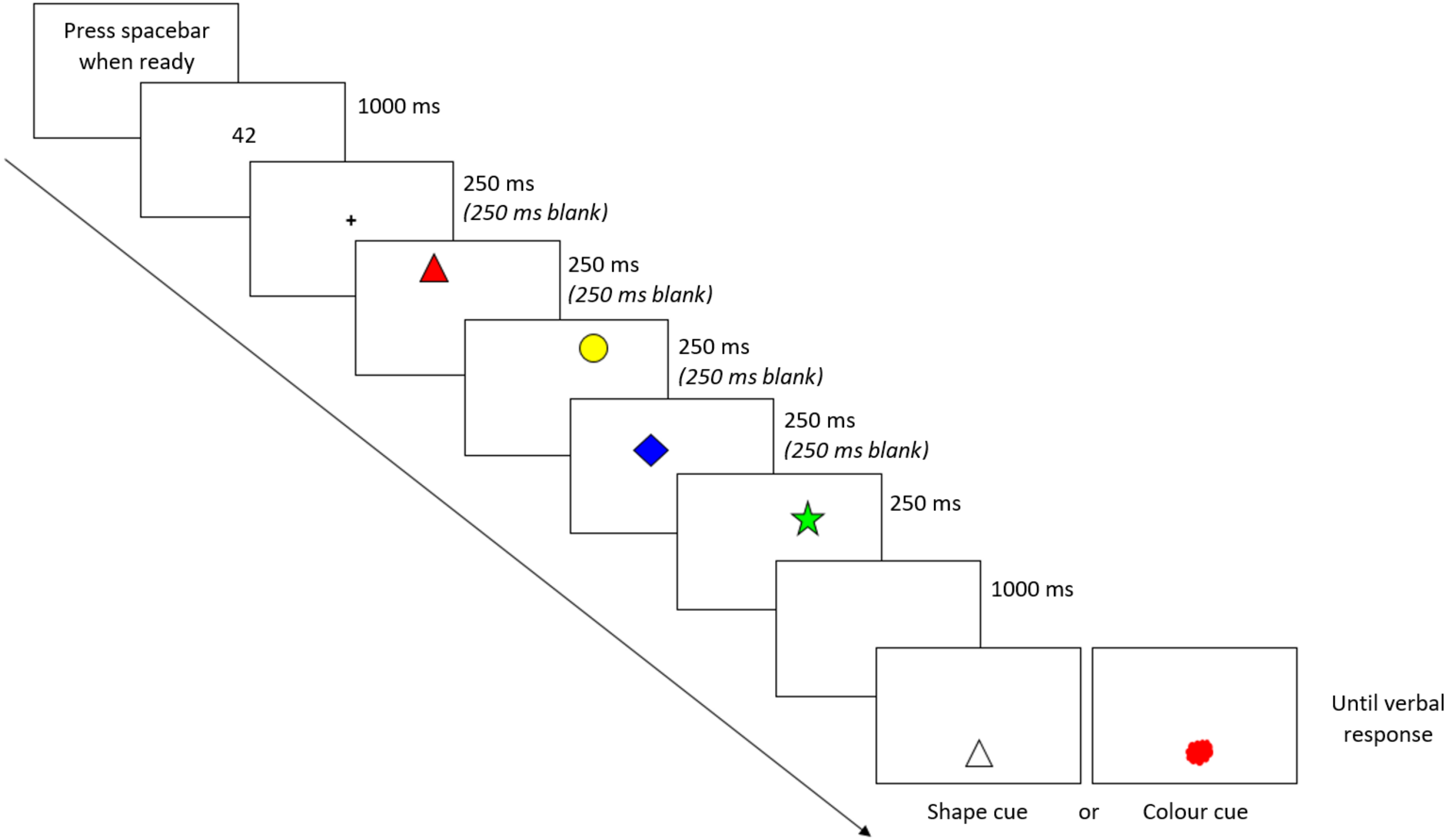

Figure 4.1 Trial procedure across prioritisation conditions. This depicts the procedure for an individual trial, in which item 1 is probed. Here, the correct answer would be ‘red’ or ‘triangle’ for the shape and colour cue trials, respectively. Stimuli are not drawn to scale.

As noted in Section 3.5.1, the procedure was based on Hu et al. (2016). Participants pressed the spacebar to begin each experimental trial. A fixation cross was shown in the centre of the screen for 500 ms followed by a 500 ms black screen. A two-digit number was then shown for 1000 ms, which the participant immediately began to repeat out load for the duration of the trial. The experimenter demonstrated the rate at which participants should repeat the number, at a rate of approximately two repetitions per second. Repetitions were recorded manually by the experimenter. Following a 250 ms blank screen, each study item was presented for 250 ms, separated by blank screens for 250 ms. Each item was presented at the corner of an invisible square at the top of the screen, in a randomised spatial order. A 1000 ms blank screen followed the final sequence item before the test probe was presented at the centre of the bottom half of the screen. Participants responded to the cue by saying aloud the feature with which they thought it had been originally presented. The experimenter recorded their answer and tallied each repetition of the two-digit number to ensure engagement with the concurrent task. Participants were debriefed following the experimental phase.

4.3.4 Data analyses

Analyses followed the general approach detailed in Section 3.4.2. Although trait cognitive anxiety was the main variable of interest, as per the preregistration, it was also necessary to determine whether anxiety dimension influences the findings. Therefore, results are provided for the main analyses focusing on trait cognitive anxiety, as well as exploratory analyses focused on trait somatic anxiety and multilevel modelling, which treated trait cognitive and somatic anxiety as continuous variables. Bonferroni corrections were applied automatically in SPSS 27 for pairwise comparisons. Where paired samples t-tests were conducted, the applied correction is noted for the specific analysis. Bayes factors are also reported to fully complement the results of the main analyses.

4.4 Study 1 – Results

4.4.1 Data checking

Missing values and multiple responses to individual items were identified for the STICSA-Trait. In the cognitive subscale, three participants did not provide responses to one item, while one participant made multiple responses to an individual item. In the somatic subscale, two participants made multiple responses to individual items. One response was missing in response to the stress subscale of the DASS. In each case, participants with multiple responses or missing responses in a particular scale were removed from analyses including that scale.

4.4.2 Articulatory suppression

Separate 3 (trait anxiety group; low, moderate, high) x 3 (prioritisation instruction; control, prioritise item 1, prioritise item 4) mixed ANOVAs were conducted, including trait cognitive and somatic anxiety groups, to assess whether the mean repetition of the two-digit number varied by anxiety level or condition, collapsed across serial position. There were no significant main effects and no interactions, indicating consistency of repetition throughout the task (all $p > .50$). Data are displayed in Table 4.2.

Table 4.2 Mean number of articulatory suppression repetitions (with *SD*s) by trait anxiety group and instruction condition.

		Control	Prioritise 1	Prioritise 4
Trait Cognitive				
	Low	4.75 (1.37)	4.81 (1.43)	4.69 (1.44)
	Moderate	5.09 (1.65)	4.99 (1.53)	5.11 (1.70)
	High	4.57 (1.23)	4.65 (1.35)	4.64 (1.14)
Trait Somatic				
	Low	4.56 (1.43)	4.59 (1.45)	4.53 (1.58)
	Moderate	5.00 (1.45)	4.98 (1.48)	5.06 (1.47)
	High	4.78 (1.38)	4.71 (1.28)	4.71 (1.16)

4.4.3 Performance effectiveness

Recall accuracy (proportion of correct responses) and the proportion of error types (within-sequence confusions, extra-sequence intrusions) were each analysed using 3 (trait cognitive anxiety; low, moderate, high) x 3 (prioritisation instruction; control, prioritise 1, prioritise 4) x 4 (serial position; 1, 2, 3, 4) mixed factorial ANOVAs (see Appendix D for correlations amongst key variables).

Although memory for both shape and colour features was tested, an initial 4-way ANOVA that also included feature type as an independent variable indicated that this only significantly interacted with serial position, $p < .001$, and did not affect the significance of any potential two-way interactions between the other independent variables, or the three-way interaction. Thus, data by feature type were collapsed. Omissions and extra-set intrusions were rare, each comprising 0.2% of all responses, and were therefore not analysed further.

Mean accuracy data are presented in Figure 4.2. There was a main effect of serial position, $F(1.97, 130.28) = 100.43$, $MSE = .088$, $p < .001$, $n^2_p = .60$, $BF > 10{,}000$, which was strongly supported by the Bayesian analysis, but no other significant main effects or interactions (all other $p > .18$, all other $BF < .10$). Bonferroni-corrected pairwise comparisons indicated a significant recency effect across conditions and groups, strongly supported by the Bayesian analyses, with a greater proportion of correct responses at position 4 ($M = 0.72$, $SD = 0.15$) than at position 1 ($M = 0.42$, $SD = 0.17$), position 2 ($M = 0.33$, $SD = 0.14$) and position 3 ($M = 0.42$, $SD = 0.14$; all $p < .001$, all $BF > 10{,}000$).[3] Accuracy was also significantly lower at position 2 than at positions 1 and position 3 (both $p < .001$, both $BF > 10{,}000$), all differences again with strong support from the Bayesian analyses. There was no significant difference in accuracy between positions 1 and 3 ($p = 1.00$, $BF = 0.03$).

[3] Including depression as a covariate did not change the pattern of significant findings (all non-significant $p > .06$), nor did including stress as a covariate (all non-significant $p > .11$). The pattern of significant findings also remained the same when when excluding participants who reported currently taking medication for anxiety and/or depression ($N_{EXCLUDED} = 7$; all non-significant $p > .07$).

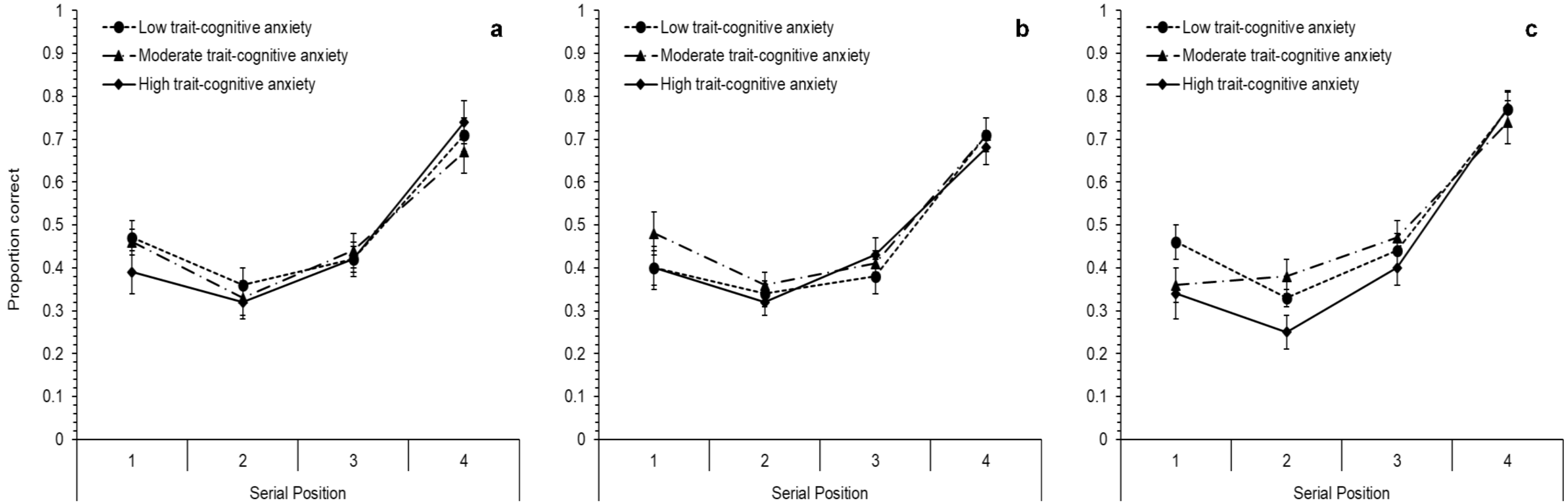

Figure 4.2 Mean proportion correct responses (± *SE*) by trait cognitive anxiety group and serial position in the: **a** control condition, **b** prioritise item 1 instruction condition, **c** prioritise item 4 instruction condition.

Main effects of serial position were also found when examining both within-set confusion and memory set intrusion error data (see Table 4.3). Data for within-sequence confusions showed the same pattern as found for proportion correct responses, with only a main effect of serial position observed, $F(2.50, 165.10) = 73.65$, $MSE = .041$, $p < .001$, $n^2_p = .53$, $BF > 10{,}000$ (all other $p > .23$, all other $BF < .10$). Here, there were significantly fewer errors at position 4 ($M = .20$, $SD = .10$) than at position 1 ($M = .39$, $SD = .13$, $p < .001$, $BF > 10{,}000$), position 2 ($M = .46$, $SD = .12$, $p < .001$, $BF > 10{,}000$), and position 3 ($M = .41$, $SD = .11$, $p < .001$, $BF > 10{,}000$) , as well as significantly more errors at position 2 than at position 1 ($p = .001$, $BF = 285$) and position 3 ($p = .009$, $BF = 25.46$). Regarding memory set intrusions, the effect of serial position was also significant, $F(3, 198) = 32.27$, $MSE = .016$, $p < .001$, $n^2_p = .33$, $BF > 10{,}000$ (all other $p > .23$, all other $BF < .11$). There were significantly fewer errors at position 4 ($M = .06$, $SD = .06$) than at position 1 ($M = .17$, $SD = .08$, $p < .001$, $BF > 10{,}000$), position 2, ($M = .17$, $SD = .09$, $p < .001$, $BF > 10{,}000$), and position 3 ($M = .15$, $SD = .08$, $p < .001$, $BF > 10{,}000$), while there were no differences between positions 1, 2 and 3 (all $p > .71$, all $BF < 0.12$).

Table 4.3 Means (with *SD*s) for within-sequence confusions and memory set intrusions within each anxiety group, serial position, and prioritisation instruction condition.

	Control Instructions				**Prioritise Position 1 Instructions**				**Prioritise Position 4 Instructions**			
	Position 1	**Position 2**	**Position 3**	**Position 4**	**Position 1**	**Position 2**	**Position 3**	**Position 4**	**Position 1**	**Position 2**	**Position 3**	**Position 4**
Within-sequence Confusions												
Low Trait Cognitive Anxiety	.38 (.15)	.47 (.17)	.41 (.18)	.20 (.16)	.43 (.20)	.49 (.20)	.43 (.15)	.20 (.14)	.36 (.17)	.48 (.15)	.41 (.19)	.18 (.15)
Moderate Trait Cognitive Anxiety	.32 (.14)	.43 (.20)	.37 (.17)	.23 (.14)	.34 (.21)	.41 (.14)	.39 (.17)	.22 (.16)	.43 (.16)	.43 (.14)	.35 (.17)	.19 (.17)
High Trait Cognitive Anxiety	.39 (.22)	.53 (.21)	.43 (.15)	.18 (.17)	.39 (.20)	.43 (.13)	.37 (.18)	.21 (.12)	.44 (.21)	.46 (.15)	.40 (.18)	.21 (.13)
Memory Set Intrusions												
Low Trait Cognitive Anxiety	.13 (.11)	.15 (.13)	.16 (.12)	.08 (.09)	.13 (.10)	.15 (.14)	.16 (.12)	.09 (.11)	.17 (.15)	.14 (.11)	.12 (.13)	.04 (.07)
Moderate Trait Cognitive Anxiety	.20 (.11)	.19 (.11)	.16 (.15)	.09 (.11)	.17 (.11)	.20 (.13)	.16 (.13)	.06 (.08)	.20 (.12)	.17 (.15)	.16 (.14)	.05 (.09)
High Trait Cognitive Anxiety	.19 (.15)	.13 (.10)	.12 (.10)	.06 (.12)	.15 (.13)	.22 (.14)	.14 (.10)	.08 (.08)	.15 (.18)	.22 (.18)	.18 (.16)	.04 (.06)

4.4.4 Exploratory analyses

Trait somatic anxiety. To assess the specificity of effects to the cognitive dimension of trait anxiety, the main ANOVAs were conducted again, but with the groups created according to trait somatic anxiety scores (see Table 4.1). Again, there were no significant effects observed (all $p > .10$, all $BF < 1.16$), other than the effect of serial position reported in the trait cognitive analyses, across proportion correct, within-sequence confusions, and memory set intrusions.

Multilevel modelling. To explore potential linear effects of anxiety as a predictor of performance, multilevel models were constructed, treating trait cognitive anxiety as a continuous independent variable. Mean-centred trait cognitive anxiety scores, strategy instruction, and serial position served as fixed-effects predictors. Terms were entered factorially, at a single level, including each main effect, the two-way interactions, and the three-way interaction. An unstructured repeated covariance structure was selected, in line with multivariate repeated-measures ANOVA (Hoffman & Rovine, 2007). Participant identifier served as a random factor. Separate analyses included trait cognitive and trait somatic anxiety (Edwards et al., 2017; Spalding et al., 2021). The full outcomes for tests of fixed effects in the multilevel model analyses can be viewed in Appendix E. For the analysis with trait cognitive anxiety, the pattern of results reflected those of the main analyses, with a significant effect of serial position on proportion of correct responses ($p < .001$) and no other significant effects (all other $p > .07$). For the analysis with trait somatic anxiety, there was again a significant effect of serial position ($p < .001$) and no other significant effect (all other $p > .15$).

4.5 Study 1 – Discussion

Study 1 investigated the extent to which trait anxiety, especially the cognitive dimension, impacted on visual feature binding through primarily top-down attentional control. On the basis of Attentional Control Theory (Eysenck et al., 2007), it was predicted that participants measuring high in anxiety would exhibit poorer visual feature binding memory performance. More specifically, we predicted that they would demonstrate poorer recall of items that rely to a greater extent on executive resources in order to be maintained while encoding new information (i.e. items presented earlier in a 4-item sequence). It was also predicted that highly anxious participants would show less strategic benefit of directing their attention towards specific items in the memory sequence (i.e. prioritising either the first or fourth object). This is because strategic direction in working memory has been associated with greater available executive resources (see Hitch et al., 2020).

The results did not support a visual binding deficit associated with higher levels of anxiety, nor were there any effects relating to the strategy instruction manipulation. As expected, though, we observed a significant recency effect, which is consistent with previous visual feature binding literature (Allen et al., 2006; Allen et al., 2014; Hu et al., 2014; Hu et al., 2016).

4.5.1 Anxiety and strategic prioritisation

Regarding the lack of a significant three-way interaction between anxiety, serial position and prioritisation instruction, it is evident that the ability to focus on specific items in the memory sequence according to task instructions was not affected by anxiety levels. Performance did not vary by prioritisation condition, and this in turn was not affected by anxiety group. The lack of interaction between anxiety, serial position and prioritisation instruction also indicates that this result is not due to positive effects of the strategy instruction on early-item recall for the high anxiety group. That is, it is not the case that the high anxiety group saw a benefit of the instruction that brought their performance up to the level of the other groups. This is particularly important in the context of ACT, according to which participants reporting higher levels of anxiety may employ compensatory performance strategies when motivated by appreciable incentives (Berggren & Derakshan, 2013; Eysenck et al., 2007; Eysenck & Derakshan, 2011). It may be that the point incentive for correct recall of specific items was not sufficient to encourage greater effort, nor did the task encourage greater effort from participants by encouraging intentional engagement. Indeed, previous motivational manipulations shown to affect performance differently at varying levels of anxiety have typically been more tangible, in the form of monetary rewards (e.g. Eysenck, 1985, Hardin et al., 2009) or the suggestion that the task involved is an indication of intelligence levels (Hoshino & Tanno, 2017). Comparing the mean accuracy data in the present study with Hu et al. (2014; Experiment 4) and Hu et al. (2016; Experiment 1), it would appear that mean performance levels were similar between the studies when participants were incentivised to remember the most recent item in the memory sequence under low load. However, performance did not increase at earlier serial positions in the present study as they did in these other studies when participants were incentivised to remember the first item in the memory sequence. It is possible that the task was too difficult for participants to see improvements to their performance for the first item in the sequence (see Section 4.5.4

for further discussion of potential study limitations).

4.5.2 Anxiety and serial position

Regarding the lack of effects of anxiety on top-down attentional control, there are several possibilities for this outcome. One possibility is that trait anxiety – either cognitive or somatic – does not equate to an additional executive load in visual working memory. That is, it does not simply reduce top-down control due to a greater limitation placed on executive resources, at least in this specific paradigm and within this participant sample. Sequential binding tasks should incur an executive demand as new objects must be encoded in working memory while old objects are maintained (e.g. Allen et al., 2014; 2017; see also Hitch et al., 2020). Furthermore, effects of concurrent executive load have previously been observed in sequential binding studies, wherein simultaneous performance of a backwards counting task resulted in reduced recall accuracy for early, but not late, sequence items (Allen et al., 2014; Hu et al., 2014; Hu et al., 2016). In both respects, these results indicate no additional impediment of executive attention associated with trait anxiety. Had trait anxiety reduced available executive resources, the results would have reflected a three-way interaction where the high anxiety group perform worse at positions earlier in the memory sequence, and saw less benefit, or no benefit at all, to strategizing specific serial positions as compared to the other groups. Even though it would appear that the strategy instruction did not affect performance in any of the groups in this study, a two-way interaction would still have been expected where the high trait anxiety group showed significantly lower levels of recall accuracy, especially for early-sequence items. It is therefore reasonable to suggest that the process of maintaining earlier items while encoding newer items primarily reflects the updating of working memory. The sequential binding task requires participants to maintain older representations while simultaneously encoding newer representations, but does not require attentional inhibition of irrelevant stimuli, switching between tasks or task sets, or removing no-longer relevant items (at least within a trial), as per the *n*-back task (Kirchner, 1958). As discussed in Section 2.4.1, inhibition and shifting are the two attentional functions most commonly shown to be affected by anxiety, with less evidence indicating that updating is also impaired (Berggren & Derakshan, 2013; Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011).

4.5.3 Anxiety and visual feature binding

Looking to evidence from the few previous studies that have examined the relationship between anxiety and visual feature binding specifically, there are certain methodological discrepancies that may help to explain the lack of an effect of anxiety on visual working memory here. Jaiswal et al. (2018) found that participants reporting high trait anxiety and low trait mindfulness were less accurate, less sensitive to detecting change, and demonstrated lower working memory capacity in a change detection task requiring colour-location binding. This could suggest that binding modality may have played a role. The present study required binding of purely visual features independent of the spatial location of stimuli. A meta-analysis by Moran (2016) indicated that anxiety reliably affects visuospatial, but not visual, working memory. This outcome could explain why Jaiswal et al. (2018) observed an effect while one was not observed here. The outcome also provides further support for an impact of anxiety on visuospatial, but not purely visual, working memory. Elsewhere, Moreno et al., (2015) have found an effect of worry on overall task response times, while Spalding et al. (2021) have found an effect of trait anxiety on correct response times. In each case, although the task involved a feature binding condition, the effects were observed across both binding and feature memory. Thus, the fact that no association between visual working memory performance and anxiety was observed here may reflect that anxiety primarily affects response efficiency rather than effectiveness in working memory, in line with ACT (Eysenck et al., 2007). That is, while anxiety may incur an additional executive load, this is more likely to be observed in slower, but no less accurate, responses, with more effort being required by those with higher anxiety in order to achieve this (Berggren & Derakshan, 2013). It should also be noted that each of these studies used a change detection or single probe recognition paradigm to assess performance, rather than cued recall, and it is therefore possible that recognition memory is more sensitive to effects of anxiety than recall. Logie et al. (2009) have noted that performance in cued recall binding tasks may require not only visual memory for the cued object, but also memory for the correct verbal response at test. Cued recall in conjunction with the relatively high demands of sequential presentation of stimuli, as compared with simultaneous presentation, may mean that group differences were masked by this relatively high demand on cognitive processes, which may require verbal working memory and long-term semantic memory.

4.5.4 Limitations

Alongside the above differences in performance outcomes between the present study and previous studies of anxiety and binding, there are other potential methodological limitations that must be considered. A main limitation with respect to testing the main hypothesis is the lack of a significant strategic prioritisation effect. This suggests that it is unlikely that the task manipulation impacted on performance as intended in the present study, as there was no effect of the prioritisation instruction regardless of anxiety group. It could also be argued that the absence of a significant effect of trait anxiety can be attributed to floor effects, with performance for the first three serial positions consistently at or below 50% in each anxiety group. If we are to observe an additional deficit for these items resulting from high anxiety serving as an additional cognitive load, it may be necessary to refine task paradigms to allow greater room for variations in performance. However, Hu et al. (2016) found a significant reduction in performance in a high concurrent load condition in comparison to a low load condition which yielded similar performance levels as observed here, in a binding task employing the same method of stimulus presentation and recall. They were also able to observe increases in this level of performance when participants were encouraged to remember the first item in the memory sequence, suggesting that performance in the present study was as expected relative to previous work. As suggested in Section 4.5.1, it is possible the instructions given were not sufficient to encourage prioritisation in the present sample, or the task was too difficult to allow participants' performance to improve as they attempted to prioritise the first memory item.

It is also important to address whether the range of anxiety scores observed within the present sample was of a sufficient range to observe differences between groups. Indeed, as detailed in Section 4.3.2, scores within the high trait cognitive and somatic anxiety groups were all above the respective cut-off scores of 23 and 18 recommended by Van Dam et al. (2013) in identifying cases of probable anxiety disorders. Furthermore, mean trait cognitive and trait somatic anxiety scores reported by participants in the high anxiety groups were within the range reported by participants with anxiety disorders (Grös et al., 2010). Therefore, it is unlikely that a lack of observed effects of anxiety on performance were a result of an insufficient range in anxiety scores, or insufficiently high scores in those classified as high in trait anxiety.

A final issue that may have impacted the pattern of significant findings was the observed study power. While the sample size was sufficient to detect medium effects of the hypothesised three-way interaction, it is possible that a smaller significant effect was missed. Looking at the pattern of data across anxiety groups and the repeated-measures variables in Figure 4.1, the high trait cognitive anxiety group were consistently the lowest performing group at the earlier serial positions, but it is not possible to say that significant between-groups differences would have been observed with a larger sample.

4.6 Chapter summary

Study 1 suggests that, contrary to ACT (Eysenck et al., 2007), relatively high levels of trait cognitive anxiety – or indeed, trait somatic anxiety - does not affect the binding of sequentially-presented visual features. Neither was there a significant effect of anxiety on the extent to which participants could strategically direct their attention according to task instructions. Although note that, generally, prioritisation effects were not observed across the entire sample, despite having been observed in the literature previously (Atkinson et al., 2020; Hitch et al., 2018, Hu et al., 2014; Hu et al., 2016). Overall, then, there was no evidence supporting the view that anxiety negatively impacts visual working memory through the reduction of available executive resources. The study differs from previous research assessing the relationship between anxiety and visual working memory, focusing on the effects of anxiety on memory for sequentially presented information, rather than simultaneously presented information as has been typical in previous studies (see Section 2.5). There is still scope to expand on the paradigm used here, however, by introducing more tangible rewards for task performance, or more explicitly encouraging participants to intentionally engage with stimuli, which would be useful for future research. Adopting similar outcome measures to previous studies investigating anxiety (e.g., Moreno et al., 2015; Spalding et al., 2021) may also help to clarify the specificity of previously observed effects of anxiety to change detection/probe recognition and performance efficiency outcomes (see Section 2.5.4). Furthermore, there is a need to assess the impact of bottom-up attention within the same paradigm, in order to address recent assumptions about the role of attentional processes in visual working memory. The role of bottom-up attention is the focus of the study reported in Study 2 (Chapter 5). This first study represents an informative first step towards considering the impact of anxiety on performance of current visual working memory paradigms and, together with the results of Study 2 reported next, provides insight into the top-down and bottom-up attentional mechanisms that are theoretically affected by anxiety, and the implications for subsequent visual working memory performance.

5 Study 2 - Impacts of anxiety on bottom-up attentional interference in visual feature binding

5.1 Chapter overview

Following on from the focus on top-down attention in Study 1, Study 2 also adopted a sequential, cued-recall, visual feature binding paradigm. However, this study incorporated further manipulation of stimulus presentation to assess the role of anxiety and bottom-up attention in binding. In this version of the task, participants completed three blocks of trials. In two blocks they were presented with to-be-ignored stimuli following presentation of the memory array. The to-be-ignored stimuli were plausible or implausible 'suffixes'. Plausible suffixes were those with features taken from the broader pool of potential memory features, but not the memory sequence. Implausible suffixes were those with novel features, i.e., features that were not part of the pool of potential memory features. Participants were again grouped according to relatively low, moderate, or high anxiety scores. It was predicted that participants reporting high trait cognitive anxiety would demonstrate lower performance accuracy at early serial positions compared to the other groups. Furthermore, it was expected that the high anxiety group would show the greatest interference from suffixes, specifically in the plausible suffix condition. No effects of trait cognitive or trait somatic anxiety were found on recall performance. Each type of suffix caused a significant decrease in performance compared to a control condition featuring no suffix. Serial position data were in line with previous research on visual binding, with a serial position curve demonstrated across conditions. Specifically, performance was significantly lower at serial position 2 than at the other serial positions, while performance at serial position

4 was significantly higher than at the other positions. The findings are in line with Study 1, failing to support the hypothesis that trait anxiety negatively affects visual working memory, even in the context of increased distraction from irrelevant stimuli.

5.2 Study 2 – Introduction

Study 1 (see Chapter 4) adopted a sequential binding paradigm in which participants were encouraged to remember specific objects in the memory sequence, in order to assess the potential impacts of anxiety on top-down attention. Based on the assumption that anxiety reduces top-down executive control (e.g. Eysenck et al., 2007), it was expected that high levels of trait anxiety would be associated with a reduced benefit of directing attention towards specific items as compared to lower levels of trait anxiety. No evidence was found for an effect of anxiety in Study 1, suggesting that anxiety does not sufficiently disrupt attentional control so as to produce performance deficits in that particular visual feature binding paradigm. Study 2 was designed to assess whether higher anxiety would be associated with increased interference from irrelevant stimuli in the same sequential binding task, testing the assumption that high anxiety is associated with difficulty inhibiting irrelevant information from capturing attention (e.g., Eysenck et al., 2007).

5.2.1 Bottom-up attention in visual feature binding

Studies focusing on sequential binding have found evidence for a distinct role of bottom-up attention in visual feature binding. Interference effects of newly presented stimuli on recall of previously presented stimuli within a to-be-remembered memory array extend to interference from irrelevant, to-be-ignored suffixes. These suffixes, presented following the memory array, reduce recall of most recently presented to-be-remembered item within a sequence (Baddeley et al., 2011). The effects of visual suffixes depend on the characteristics of their features. Plausible suffixes are those consisting of features that are drawn from the same feature set as the memory items. Participants are typically made aware of these prior to a binding task and know that these could be features that make up the items in the memory array. Implausible suffixes are those that consist of features not initially shown in the pool of potential memory features. Evidence has indicated that the presentation of an implausible suffix disrupts visual working memory for individual features and bindings equally, and that, by comparison, plausible suffixes disrupt binding to a greater degree (Ueno, Allen et al., 2011; Ueno, Mate et al., 2011; Hu et al., 2014). Plausible suffixes seemingly capture perceptual attention automatically, evidenced by equivalent interference observed for suffixes in which either one or both visual features are plausible (Ueno, Mate et al., 2011).

5.2.2 Anxiety and perceptual distraction

There is evidence that suggests less efficient, and potentially less effective, attentional inhibition of visual distractors (see Section 2.4.1) at high levels of trait and state anxiety. Several studies studies using anti-saccade tasks have found that participants reporting high levels of trait anxiety demonstrate reduced efficiency, as shown by longer saccade latencies away from nontargets to targets (Ansari & Derakshan, 2010; Ansari & Derakshan, 2011a; Derakshan et al., 2009a). Similar findings have been observed in a study comparing individuals diagnosed with generalized anxiety disorder and control participants (Jazbec et al., 2005) and studies that have induced higher state anxiety (Garner et al., 2011; Garner et al., 2012). Performance accuracy has also been shown to be lower at high levels of trait anxiety when distractor stimuli are threatening (Garner et al., 2009), or anxious individuals also self-report low attentional control (Hutley et al., 2010). Visual search studies have also shown that presentation of a distractor during the task increases response times at high levels of trait anxiety compared to low (Moser et al., 2012), an effect exacerbated as memory load increases (Sadeh & Bredemeier, 2011).

Anxiety appears to be reliably associated with increased susceptibility to attentional distraction, and this susceptibility has been shown to extend to the inefficient filtering of distractors from working memory (see Section 2.5.1). Qi, Ding, et al. (2014) compared high and low trait anxiety scorers' working memory capacity, task response times, task response accuracy, and contralateral delay activity (CDA) amplitudes in a change detection paradigm. CDA amplitudes increase with increased representations held in working memory, up to the level of the individual's working memory capacity. Performance was compared across memory for the orientation of either two red rectangles, four red rectangles, or two red rectangles with two green distractor rectangles simultaneously presented. Although they found no effect of anxiety on behavioural performance across conditions, late CDA amplitudes for the low trait anxiety group significantly increased between the low load and distractor conditions, and again from the distractor condition to high load condition. However, in the high trait anxiety group CDA amplitudes in the distractor condition and high load condition were not significantly different, and both were significantly higher than the low load condition. Filtering efficiency scores, calculated as the difference between the high load and distractor condition amplitudes divided by the difference between the high load and low load amplitudes, also suggested that high trait anxiety was associated with less efficient filtering of distractors. These results followed similar filtering efficiency data obtained by Stout et al. (2013), who found that filtering efficiency of threatening faces – as compared to neutral faces – was reduced in both a high trait anxiety group and low trait anxiety group, but that the effect was greater in the high group. Stout et al. also observed equivalent outcomes for response time data, raising the possibility that behavioural outcomes may be more likely to be affected when stimuli are emotionally salient.

Effects of anxiety on behavioural indicators of distractor processing in working memory have emerged when specific dimensions of anxiety are considered. Stout et al. (2015) employed a similar methodology to Stout et al. (2013) and found that while overall trait anxiety was associated with a general cost to filtering from working memory, worry – as measured by both specific items within the State-Trait Anxiety Inventory (Spielberger et al., 1970) as well as the Penn State Worry Questionnaire (Meyer et al., 1990; see Section 3.2) – was specifically associated with reduced filtering of threat-related distractors. The non-worry items of the anxiety measure were associated specifically with the filtering cost of neutral distractors. This particular outcome highlights the importance of considering the specific dimensions of anxiety separately when determining effects of anxiety on visual working memory (see Section 3.2). Recent evidence for an association between anxiety and impaired filtering from working memory comes from Berggren (2020), who found that high trait anxiety was associated with reduced filtering of neutral distractors specifically in a condition where state apprehension was induced via threat of an aversive noise.

5.2.3 Hypotheses

Study 2 adopted the paradigm used by Hu et al. (2016) in order to assess the potential effects of anxiety on visual working memory through primarily bottom-up distractor interference. Participants were asked to complete a visual feature binding task in which, under certain conditions, they were presented with a to-be-ignored visual suffix following the memory sequence. If anxiety is associated with less efficient and effective filtering of distractors, as described above, there should be an increased effect of irrelevant stimulus presentation with higher anxiety. Specifically, a three-way interaction was predicted. It was predicted that performance in the binding task would be reduced to a greater extent in the plausible suffix condition as compared to a control condition in a high trait anxiety group. The high anxiety group were also predicted to exhibit a greater drop in performance at the final serial position in the memory sequence when a suffix was presented. Further to this, and as predicted in Study 1, participants classified as highly anxious should demonstrate a reduction in memory for early sequence items beyond those of low anxiety scorers overall. This would occur if they are unable to maintain earlier memory representations or inhibit distraction from items presented later in the sequence, or the suffix itself. Although an implausible suffix condition was also included, there were no specific predictions made as to the effect this may have between anxiety groups, although it is conceivable that implausible suffixes would interfere to a greater extent with the performance of participants reporting higher levels of anxiety.

5.3 Study 2 – Method

This study was preregistered with the Open Science Framework following prior to data collection. The pre-registration for the study can be found at https://osf.io/7p5kq, with underlying data to be made available following publication.

5.3.1 Participants

Seventy-two young adults were initially recruited, with one participant's data removed as they reported significant problems with their memory. Therefore the sample consisted of 71 participants (16 male, 54 female, 2 preferred not to say) aged 18-35 years (M = 23.18, SD = 3.93). Mean years of education was 16.47 (SD = 2.55)[4]. Participants were recruited from the undergraduate participant pool for Psychology at the University of Strathclyde, social media, and through opportunity sampling. All participants reported normal/corrected-to-normal vision, and no memory impairments. A retrospective power analysis conducted using MorePower 6.0 (Campbell & Thompson, 2012) indicated that 71 participants was sufficient to detect a medium-sized effect ($n^2_p = .06$) for a three-way interaction ($\alpha = .05$, power = .95).

5.3.2 Design

A 3 (anxiety group; low, medium, high) x 3 (suffix type; control, plausible, implausible) x 4 (serial position; 1, 2, 3, 4) mixed design was used. Groups were determined by a split of anxiety scores following completion of data collection, as

[4] Two participants did not indicate their years of education completed.

described in Section 3.4.2 (see Table 5.1 for demographics by trait anxiety groups). In each case, the high trait anxiety group reflected scores above a recommended cut-off for determining probable cases of clinical anxiety using the STICSA (> 23 on the cognitive subscale, > 18 on the somatic subscale van Dam et al., 2013) and mean scores were within a range of scores previously identified in participants with anxiety disorders. While the cognitive dimension of trait anxiety was of primary interest (see Section 3.2.2), analyses were also run using trait somatic anxiety in order to assess the specificity of any significant outcomes to the different anxiety dimensions (e.g. Spalding et al., 2020).

Table 5.1 Participant demographic information by anxiety group in Study 2

	N	**Anxiety** **Min–Max, *M* (*SD*)**	**Age** ***M* (*SD*)**	**Sex** **(M:F)**	**Yrs Education** ***M* (*SD*)**
Trait Cognitive	70*				
Low	24	11-17, 15.04 (1.73)	23.21 (4.73)	3:21	16.83 (2.46)
Moderate	26	18-23, 20.35 (1.60)	22.23 (3.20)	8:18	15.80 (2.08)
High	20	24-35, 27.90 (2.95)	24.14 (3.68)	5:14#	16.60 (2.91)
Trait Somatic	71				
Low	22	11-15, 13.77 (1.44)	24.91 (4.20)	8:13*	16.90 (2.88)
Moderate	19	16-18, 17.00 (0.82)	22.89 (4.27)	3:16	15.94 (2.01)
High	30	19-32, 22.42 (3.29)	22.13 (3.16)	5:25	16.48 (2.62)

NB: values based on **N*-1, #*N*-2, due to missing data

The dependent variables were memory accuracy (proportion correct recall of the accompanying feature of the memory cue) and proportion of errors. For the plausible suffix condition, errors were categorised as either within-sequence confusions (incorrect recall of another feature in the sequence), suffix intrusions (incorrect recall of a feature that was part of the suffix), memory set intrusions (incorrect recall of a feature in the wider memory set), or extra-set intrusions (incorrect recall of a novel feature not present in the memory set).

In the implausible suffix condition, however, participants were not presented with labels for the implausible suffixes prior to completing the experimental task. Therefore, there was some ambiguity in responses made by participants in this condition due to trials in which there was overlap in hues between a memory item and the suffix. For accuracy data, if there was ambiguity in a participant's response, but this ambiguity indicated a possible correct answer (e.g., if the participant said 'yellow' when the correct answer was yellow, but the suffix presented was a paler shade of yellow) the response was marked as being correct, as the participant had provided the correct label name. For error data, responses that could have been interpreted as either an incorrect within-sequence response or suffix response (e.g., a participant responded 'yellow' when yellow was presented in the memory sequence and a paler shade of yellow was presented in the suffix) were classified as being 'either within-sequence or suffix confusion errors'. Responses that could be interpreted as either an extra-sequence response or suffix response (e.g., a participant responded 'yellow' when yellow was not presented in the memory array and pale yellow was presented in the suffix) were classified as being 'either memory pool intrusion or suffix confusion errors'. Thus, errors in the implausible suffix condition could reflect unambiguous within-sequence confusions, unambiguous suffix errors, or unambiguous memory set intrusions, but additional categories of error were *incorrect non-guessing responses (ambiguous within-sequence or suffix responses)* or *incorrect guessing or suffix interference responses (unambiguous memory set or suffix responses)*.

5.3.3 Materials

Task materials were as described in Section 3.4.3. In the case of this present study, however, there were also additional features used to form the implausible suffixes. As with the memory arrays, the features for the implausible suffixes were chosen at random without replacement. These can be viewed in Figure 5.1.

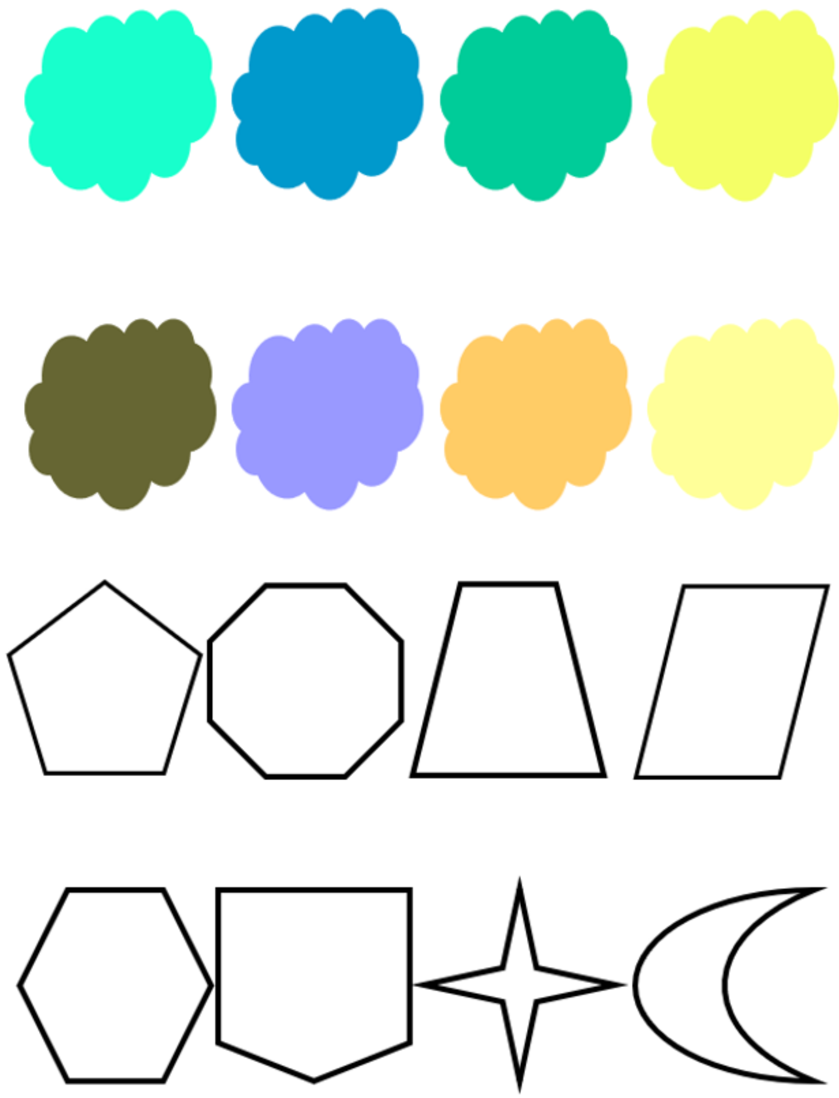

Figure 5.1 The colour and shape features, and their labels, included in the implausible suffix pool in Study 2.

5.3.4 Procedure

Participants first completed the Trait and then State versions of the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree et al., 2008), followed by the Depression Anxiety Stress Scales (DASS-21; Lovibond & Lovibond, 1995). They then completed the binding memory task. The experimental procedure was the same as in Study 1 with respect to stimulus presentation, number of trials (both practice and experimental), and trial randomisation, however in the suffix blocks, the procedure also included a blank screen for 250 ms following the final memory item, followed by a presentation of the suffix in the centre of the screen for 250 ms, then a 500 ms blank screen before the test cue was presented. Participants were informed of the suffix condition prior to starting each trial block (see Appendix F for task instructions in each block). An example trial procedure is presented in Figure 5.2.

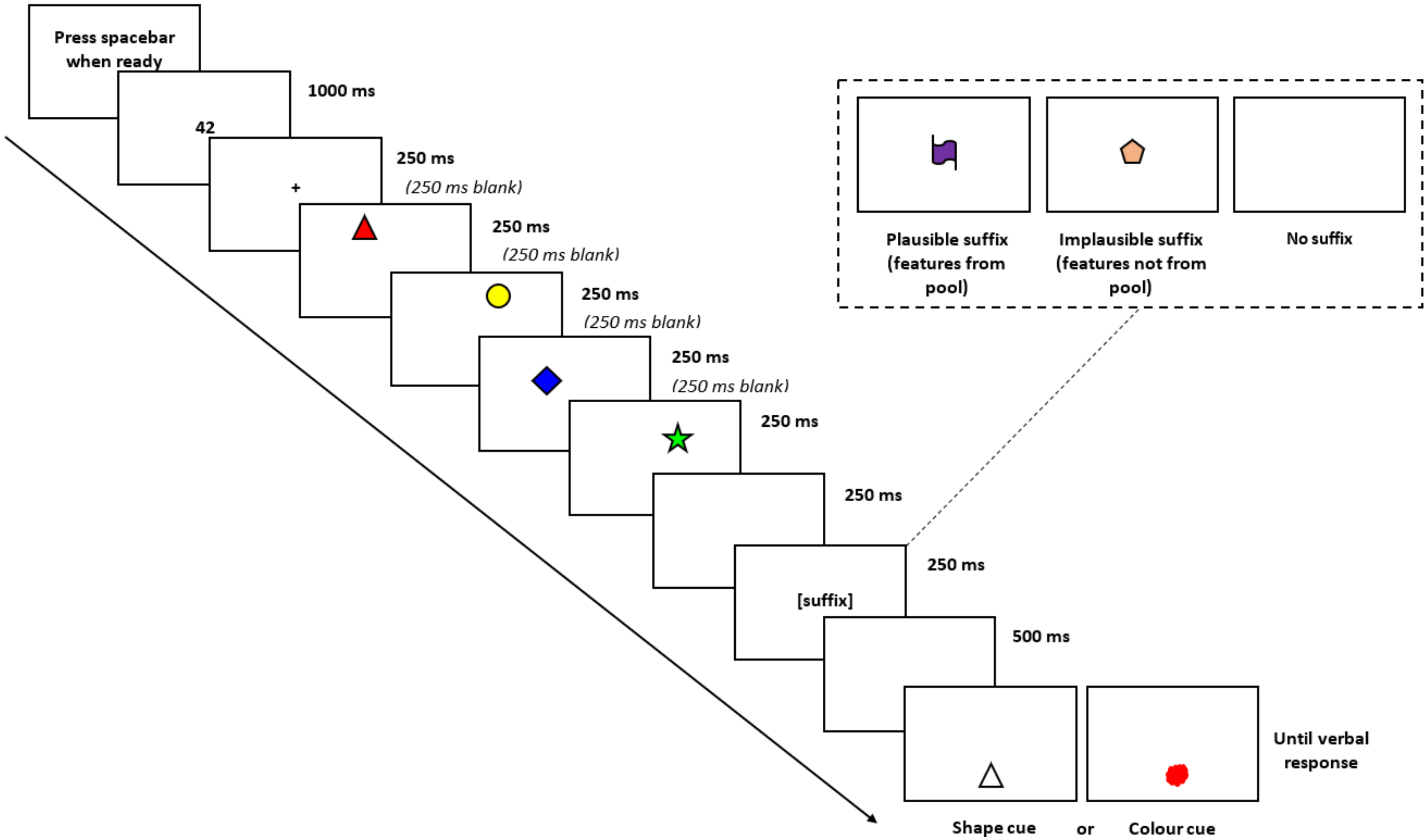

Figure 5.2 Trial procedure across prioritisation conditions. This depicts one trial procedure, in which item 1 (the red triangle) is the item cued. Correct responses in this trial would be 'red' or 'triangle' for the shape and colour cue conditions, respectively. Stimuli are not drawn to scale.

5.3.5 Data analyses

Analyses followed the general approach detailed in Chapter 3, Section 3.4.2. Although trait cognitive anxiety was the main variable of interest, as per the preregistration, it was also necessary to determine whether effects of anxiety were limited to this specific dimension of anxiety. Therefore, results are provided for the main analyses focusing on trait cognitive anxiety, as well as exploratory analyses focused on trait somatic anxiety. Bonferroni corrections were applied automatically in SPSS 27 for pairwise comparisons. Where paired samples t-tests were conducted, the applied correction is noted for that analyses. Multilevel modelling analyses, which treat trait cognitive and somatic anxiety as continuous variables, are also reported. Bayes factors are also reported to fully complement the results of the main analyses.

5.4 Study 2 – Results

5.4.1 Data checking

Due to a programming error, a single trial was removed from the plausible suffix condition for all participants. Thus, responses in the plausible suffix condition proportion correct responses were based on nine, rather than 10, trials. One participant did not provide a response to one item on the STICSA trait cognitive scale. This participant was excluded from analyses involving trait cognitive anxiety.

5.4.2 Articulatory suppression

A 3 (trait cognitive anxiety group; low, moderate, high) x 3 (suffix condition; control, plausible suffix, implausible suffix) mixed ANOVA was conducted to assess whether repetition of the two-digit number varied by anxiety level or suffix condition, or the interaction, collapsed across serial position. There were no significant main effects or interaction, indicating consistency of repetition throughout the task (all $p > .16$). Mean repetitions are displayed in Table 5.2.

Table 5.2 Mean articulatory suppression repetitions (with *SD*s) by trait cognitive anxiety group and suffix condition.

	Control	**Plausible**	**Implausible**
Low trait cognitive anxiety	4.30 (1.19)	4.49 (1.28)	4.55 (1.33)
Moderate trait cognitive anxiety	4.69 (1.39)	4.70 (1.18)	4.66 (1.01)
High trait cognitive anxiety	4.25 (0.91)	4.36 (0.86)	4.34 (0.86)

5.4.3 Performance effectiveness

An initial 2 (cue type; shape, colour) x 3 (trait cognitive anxiety group; low, moderate, high) x 3 (suffix presentation; control, plausible, implausible) x 4 (serial position; 1, 2, 3, 4) mixed ANOVA was conducted to assess whether the type of feature memory being tested significantly affected the potential interactions between the predictor variables. Focusing on the effects involving cue type; there was a significant main effect of cue type, $F(1, 67) = 20.91$, $MSE = .061$, $p < .001$, $n^2_p = .24$. Memory was better when shape cues were presented (*M* = .46, *SD* = .08) than when colour cues were presented (*M* = .40, *SD* = .09). Moreover, there was a significant interaction between cue type, anxiety group, and suffix presentation, $F(4, 134) = 2.70$, $MSE = .044$, $p = .033$, $n^2_p = .08$. Therefore, data were not collapsed across memory type as in Chapter 4. Instead, recall accuracy (proportion of correct responses) and the proportion of error types (within-sequence confusions, extra-sequence intrusions) for shape and colour memory were each analysed using a 3 (trait cognitive anxiety; low, moderate, high) x 3 (suffix presentation; control, plausible, implausible) x 4 (serial position; 1, 2, 3, 4) mixed factorial ANOVAs. Extra-set intrusions and omissions across suffix conditions were rare, totalling .03% of all responses, and were therefore not analysed further. Mean accuracy in trials in which either a shape or colour cue were presented can be viewed in Table 5.3 (see Appendix G for correlations amongst key variables).

Table 5.3 Mean proportion correct responses (with *SDs*) across anxiety groups, cue type, suffix condition, and serial position.

	Control (no suffixes)				Plausible suffixes				Implausible suffixes			
	Position 1	**Position 2**	**Position 3**	**Position 4**	**Position 1**	**Position 2**	**Position 3**	**Position 4**	**Position 1**	**Position 2**	**Position 3**	**Position 4**
Shape cues												
Low Trait Cognitive Anxiety	.56 (.26)	.38 (.19)	.50 (.26)	.74 (.23)	.41 (.25)	.26 (.22)	.39 (.24)	.59 (.17)	.43 (.27)	.27 (.22)	.46 (.16)	.61 (.22)
Moderate Trait Cognitive Anxiety	.44 (.20)	.29 (.25)	.42 (.20)	.71 (.25)	.50 (.31)	.26 (.17)	.41 (.26)	.65 (.26)	.42 (.25)	.27 (.24)	.40 (.23)	.53 (.26)
High Trait Cognitive Anxiety	.47 (.21)	.41 (.21)	.50 (.26)	.69 (.28)	.33 (.21)	.35 (.29)	.43 (.25)	.58 (.23)	.48 (.25)	.34 (.27)	.42 (.27)	.64 (.23)
Colour cues												
Low Trait Cognitive Anxiety	.46 (.27)	.31 (.23)	.43 (.22)	.67 (.24)	.29 (.18)	.28 (.17)	.32 (.19)	.50 (.30)	.39 (.24)	.23 (.22)	.34 (.22)	.55 (.26)
Moderate Trait Cognitive Anxiety	.47 (.21)	.32 (.28)	.45 (.27)	.65 (.24)	.34 (.22)	.23 (.18)	.31 (.18)	.50 (.31)	.41 (.24)	.26 (.21)	.32 (.23)	.54 (.31)
High Trait Cognitive Anxiety	.40 (27)	.40 (.25)	.47 (.24)	.69 (.22)	.39 (.26)	.33 (.28)	.37 (.24)	.49 (.33)	.36 (.22)	.24 (.21)	.37 (.21)	.46 (.30)

Shape cues. Mean accuracy data for trials in which a shape cue was presented are visualised in Figure 5.3. There was a main effect of suffix condition, $F(2, 134) = 9.58$, $MSE = .055$, $p < .001$, $n^2_p = .13$, $BF = 241.42$, and serial position, $F(2.43, 162.50) = 53.87$, $MSE = .084$, $p < .001$, $n^2_p = .45$, $BF > 10{,}000$. There were no other significant main effects or interactions, with the interaction between suffix and anxiety group, which presumably drove the initial memory type x anxiety group x suffix interaction, failing to reach significance, $p = .060$, and with no support from the Bayesian analyses, $BF = 0.01$ (all other $p > .45$, all other $BF < 0.24$).

Following-up the main effects, Bonferroni-adjusted pairwise comparisons indicated that accuracy was significantly greater in the control condition ($M = .51$, $SD = .13$) than both the plausible suffix condition ($M = .43$, $SD = .13$), $p = .001$, $BF = 197$, and implausible suffix condition ($M = .44$, $SD = .13$), $p = .003$, $BF = 40.54$, but there was not a significant difference between the plausible and implausible conditions, $p = 1.00$, $BF = 0.04$. Bonferroni-adjusted pairwise comparisons also indicated that performance accuracy was lower at position 2 ($M = .31$, $SD = .15$) than at position 1 ($M = .45$, $SD = .17$), position 3 ($M = .44$, $SD = .14$), and position 4 ($M = .64$, $SD = .17$), all $p < .001$, all $BF > 10{,}000$. There was also a significant recency effect across conditions and groups, with a greater proportion of correct responses at position 4 than at positions 1, 2 and 3 (all $p < .001$, all $BF > 10{,}000$). There was no significant difference between positions 1 and 3, $p = 1.00$, $BF = 0.04$.[5]

[5] Including self-reported depression as a covariate did not affect the pattern of significant findings regarding anxiety (all $p > .07$), but did result in the main effect of suffix condition becoming nonsignificant ($p = .075$).Including stress as a covariate did not affect the pattern of significant results (all $p > .11$).The pattern of significant findings was also the same when excluding participants who reported currently taking medication for anxiety and/or depression, or those who did not indicate their medication status ($N_{EXCLUDED} = 11$; all p involving anxiety > .14).

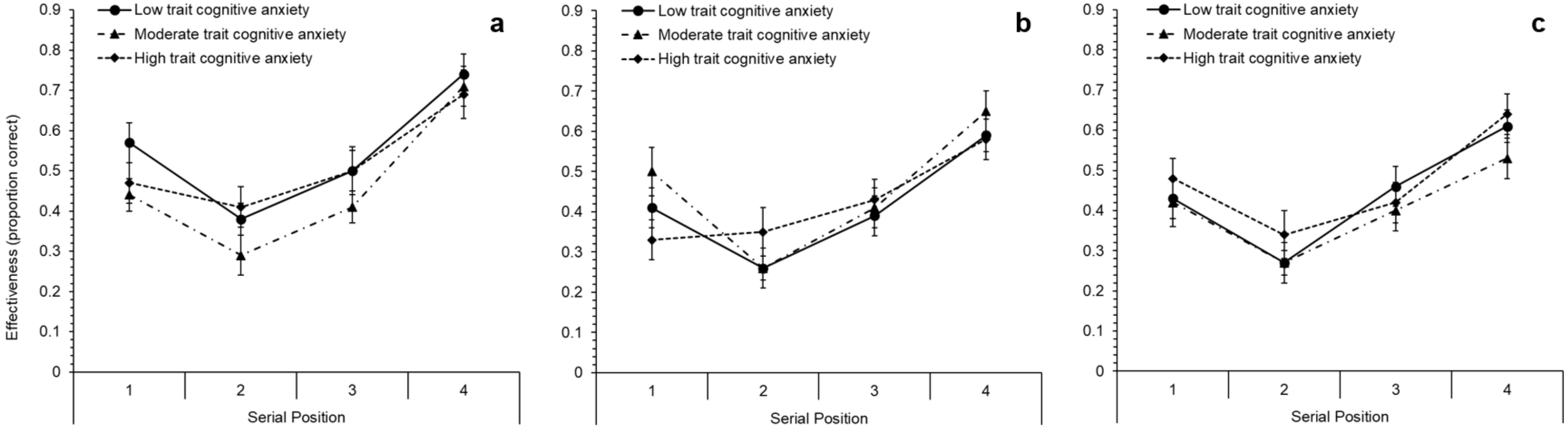

Figure 5.3 Mean proportion correct responses (± *SE*) by trait cognitive anxiety group and serial position in the: **a** control condition, **b** plausible suffix condition, and **c** implausible suffix condition.

Colour cues. There were again main effects of suffix condition, $F(2, 134) = 18.35$, $MSE = .060$, $p < .001$, $n^2_p = .22$, $BF > 10,000$, and serial position, $F(2.14, 143.11) = 42.18$, $MSE = .090$, $p < .001$, $n^2_p = .39$, $BF > 10,000$, both of which were strongly supported by the Bayesian analysis. There were no other main effects or interactions observed (all other $p > .34$, all other $BF < .04$).

Regarding the main effects, as for colour cues, Bonferroni-adjusted pairwise comparisons indicated that accuracy was significantly greater in the control condition ($M = .48$, $SD = .14$) than both the plausible suffix condition ($M = .36$, $SD = .13$), $p < .001$, $BF > 10,000$ and implausible suffix condition ($M = .37$, $SD = .13$), $p < .001$, $BF > 10,000$, but there was not a significant difference between the plausible and implausible conditions, $p = 1.00$, $BF = .05$. Bonferroni-adjusted planned comparisons also indicated that performance accuracy, again as with the colour cues, was lower at position 2 ($M = .29$, $SD = .15$) than at position 1 ($M = .39$, $SD = .16$), $p < .001$, $BF > 10,000$, position 3 ($M = .38$, $SD = .12$), $p < .001$, $BF = 412$ and position 4 ($M = .56$, $SD = .19$), all $p < .001$, $BF > 10,000$. There was also a significant recency effect across conditions and groups, as the proportion of correct responses at position 4 was also significantly greater than at positions 1 and 3, both $p < .001$, both $BF > 10,000$. There was not a difference between positions 1 and 3, $p = 1.00$, $BF = 0.05$.[6]

[6] Including self-reported depression as a covariate did not affect the pattern of significant findings (all $p > .23$) and this was also the case when including stress as a covariate (all $p > .22$). The pattern of significant findings was also the same when excluding participants who reported currently taking medication for anxiety and/or depression, or those who did not indicate their medication status ($N_{EXCLUDED} = 11$; all p involving anxiety > .22).

5.4.4 Performance errors

Error data were analysed separately according to suffix condition. This was owing to the additional categorisation of responses in the implausible suffix condition. Furthermore, the suffix conditions could not be directly compared with the control condition, in which suffixes were not presented. Initial 2 (cue type) x 3 (trait cognitive anxiety group) x 4 (serial position) mixed ANOVAs indicated that cue type did not significantly interact with trait cognitive anxiety, for either within-sequence confusions or memory set intrusions (all $p > .59$). This was also the case across error types in the plausible suffix condition (all $p > .05$) and in the implausible suffix condition (all $p > .14$). Therefore, data were collapsed across cue type. Series of 3 (trait cognitive anxiety group) x 4 (serial position) mixed ANOVAs were used to assess within-sequence confusion and memory set intrusions in each suffix condition. The mixed ANOVAs were also repeated for suffix confusions in the plausible and implausible suffix conditions.

Control condition. Mean error data in the control condition can be viewed in Table 5.4. Looking first at within-sequence confusions in the control condition, there was a main effect of serial position, $F(3, 201) = 19.26$, $MSE = .026$, $p < .001$, $n^2_p = .22$, $BF > 10{,}000$. The main effect of trait cognitive anxiety was not significant, nor was the interaction between anxiety group and serial position (both $p > .49$, both $BF < 0.11$). Bonferroni-corrected pairwise comparisons indicated that there were significantly fewer confusions at position 4 ($M = .22$, $SD = .14$) than at position 1 ($M = .36$, $SD = .16$, $p < .001$, $BF = 2064$), position 2 ($M = .43$, $SD = .18$, $p < .001$, $BF > 10{,}000$), and position 3 ($M = .36$, $SD = .18$, $p < .001$, $BF > 10{,}000$) with no other significant differences between positions (all other $p > .11$).

For memory set intrusions in the control condition, there was also a main effect of serial position, $F(3, 201) = 13.73$, $MSE = .015$, $p < .001$, $n^2_p = .17$, $BF > 10{,}000$. The main effect of trait cognitive anxiety was not significant, nor was the interaction between anxiety group and serial position (both $p > .34$, both $BF < 0.16$). Again, Bonferroni-corrected pairwise comparisons indicated that there were significantly fewer confusions at position 4 ($M = .07$, SD = .09) than at position 1 ($M = .15$, $SD = .12$, $p < .001$, $BF = 430$), position 2 ($M = .19$, $SD = .15$, $p < .001$, $BF > 10{,}000$), and position 3, ($M = .16$, $SD = .15$, $p < .001$, $BF = 794$) with no other significant differences between positions (all other $p > .39$).

Table 5.4 Mean error data (with *SD*s) in the control condition in Study 2.

	Position 1	**Position 2**	**Position 3**	**Position 4**
Within-sequence confusions				
Low Trait Cognitive Anxiety	.32 (.15)	.43 (.19)	.38 (.17)	.21 (.11)
Moderate Trait Cognitive Anxiety	.38 (.17)	.46 (.17)	.38 (.20)	.21 (.16)
High Trait Cognitive Anxiety	.38 (.16)	.39 (.19)	.34 (.17)	.25 (.18)
Memory set intrusions				
Low Trait Cognitive Anxiety	.16 (.10)	.22 (.18)	.15 (.14)	.07 (.09)
Moderate Trait Cognitive Anxiety	.17 (.13)	.19 (.13)	.16 (.13)	.09 (.11)
High Trait Cognitive Anxiety	.13 (.11)	.16 (.14)	.16 (.18)	.04 (.05)

Plausible suffix condition. Mean error data in the plausible suffix condition can be viewed in Table 5.5. For within-sequence confusions in the plausible suffix condition, there was a main effect of serial position, $F(3, 201) = 11.65$, $MSE = .026$, $p < .001$, $n^2_p = .15$, $BF > 10{,}000$. There were no other significant effects (both $p > .08$, both $BF < 0.40$). Bonferroni-corrected pairwise comparisons indicated that there were significantly fewer confusions at position 4 ($M = .29$, $SD = .17$) than at positions 1, ($M = .38$, $SD = .17$, $p = .035$, $BF = 3.00$), 2, ($M = .45$, $SD = .15$), $p < .001$, $BF > 10{,}000$), and 3, ($M = .38$, $SD = .18$), $p = .005$, $BF = 21.79$. There were also significantly fewer confusions at position 1 than at position 2, $p = .029$, $BF = 4.14$, and no other significant differences (both other $p > .06$).

For memory set intrusions in the plausible suffix condition, there was a significant effect of serial position, $F(3, 201) = 10.11$, $MSE = .010$, $p < .001$, $n^2_p = .13$, $BF = 9059$. There was no significant effect of trait cognitive anxiety or the interaction (both $p > .37$, both $BF < 0.14$). Bonferroni-corrected pairwise comparisons indicated that there were significantly fewer intrusions at position 4 ($M = .06$, $SD = .07$) than at position 1 ($M = .14$, $SD = .13$), $p < .001$, $BF = 732$, position 2 ($M = .14$, $SD = .13$), $p < .001$, $BF = 426$, and position 3 ($M = .13$, $SD = .11$), $p < .001$, $BF = 288$, with no other significant differences (all other $p = 1.00$, all other $BF < 0.15$). For suffix errors there were no significant effects of either serial position, trait cognitive anxiety group, or their interaction (all $p > .18$, all $BF < 0.16$). Note, however, that suffix errors in this condition were extremely low overall (see Table 5.5).

Table 5.5 Mean error data (with *SD*s) in the plausible suffix condition in Study 2.

	Position 1	Position 2	Position 3	Position 4
Within-sequence confusions				
Low Trait Cognitive Anxiety	.42 (.17)	.48 (.16)	.43 (.18)	.31 (.18)
Moderate Trait Cognitive Anxiety	.34 (.18)	.48 (.10)	.35 (.18)	.23 (.16)
High Trait Cognitive Anxiety	.38 (.17)	.39 (.19)	.37 (.17)	.33 (.18)
Memory set intrusions				
Low Trait Cognitive Anxiety	.12 (.08)	.11 (.12)	.13 (.09)	.07 (.07)
Moderate Trait Cognitive Anxiety	.14 (.14)	.17 (.12)	.15 (.11)	.07 (.07)
High Trait Cognitive Anxiety	.15 (.09)	.15 (.15)	.11 (.13)	.04 (.05)
Suffix intrusions				
Low Trait Cognitive Anxiety	.00 (.02)	.00 (.02)	.01 (.04)	.01 (.03)
Moderate Trait Cognitive Anxiety	.01 (.03)	.00 (.02)	.01 (.04)	.02 (.04)
High Trait Cognitive Anxiety	.01 (.03)	.01 (.03)	.02 (.04)	.03 (.06)

Implausible suffixes. Mean error data in the plausible suffix condition can be viewed in Table 5.6 and Table 5.7. Regarding within-sequence confusions in the implausible suffix condition, there was a main effect of serial position for unambiguous within-sequence confusions, $F(3, 201) = 18.51$, $MSE = .028$, $p < .001$, $n^2_p = .22$, $BF > 10{,}000$, and no other significant effects (both $p > .64$). Bonferroni-corrected pairwise comparisons indicated that there were significantly fewer confusions at position 4 (*M* = .27, *SD* = .16) than at position 2 (*M* = .47, *SD* = .19), $p < .001$, *BF* > 10,000 and position 3, (*M* = .42, *SD* = .16), $p = .001$, *BF* > 10,000. There were also significantly fewer confusions at position 1 (*M* = .34, *SD* = .16) than at position 2, $p < .001$, *BF* = 1237, and no other significant differences (other $p > .11$, other *BF* < 0.05).

For memory set intrusions, there was again a main effect of serial position, $F(3, 201) = 4.97$, *MSE* = .016, $p < .002$, $n^2_p = .07$, *BF* > 10,000, and no other significant effects (both $p > .44$). There were significantly less intrusions at position 4 *(M* = .11, *SD* = .13) than at position 1 (*M* = .17, *SD* = .12, $p = .002$, *BF* =10.41) and position 2, (*M* = .19, *SD* = .16), $p = .002$, *BF* = 7.24, with no other significant differences (all $p > .10$, all *BF* < 0.73).

For suffix errors, there was no significant effect of serial position or trait cognitive anxiety group, or their interaction (all $p > .46$, all *BF* < 0.04). Note that as with plausible suffixes, the number of suffix errors was extremely low. For responses that could have either been a within-sequence confusion or suffix intrusion, there were also no significant effects (all $p > .58$, all *BF* < .08). For responses that could either have been a suffix intrusion or memory set intrusion there were again no significant effects (all $p > .06$, all *BF* < .90). Note that as with suffix errors in the plausible condition, suffix errors in the implausible condition were again extremely low (see Table 5.6 and Table 5.7).

Table 5.6 Mean unambiguous error data (with *SD*s) in the implausible suffix condition in Study 2.

	Position 1	**Position 2**	**Position 3**	**Position 4**
Within-sequence confusions				
Low Trait Cognitive Anxiety	.35 (.14)	.43 (.18)	.40 (.17)	.28 (.16)
Moderate Trait Cognitive Anxiety	.33 (.15)	.48 (.22)	.45 (.16)	.28 (.18)
High Trait Cognitive Anxiety	.34 (.19)	.50 (.15)	.38 (.13)	.26 (.15)
Memory set intrusions				
Low Trait Cognitive Anxiety	.17 (.10)	.22 (.17)	.15 (.13)	.08 (.10)
Moderate Trait Cognitive Anxiety	.19 (.10)	.17 (.15)	.15 (.14)	.12 (.12)
High Trait Cognitive Anxiety	.16 (.14)	.18 (.15)	.19 (.14)	.14 (.16)
Suffix intrusions				
Low Trait Cognitive Anxiety	.01 (.03)	.00 (.02)	.01 (.03)	.00 (.02)
Moderate Trait Cognitive Anxiety	.00 (.02)	.00 (.02)	.01 (.03)	.01 (.04)
High Trait Cognitive Anxiety	.01 (.04)	.01 (.02)	.01 (.04)	.00 (.00)

Table 5.7 Mean ambiguous error data (with *SDs*) in the implausible suffix condition in Study 2.

	Position 1	**Position 2**	**Position 3**	**Position 4**
Within-sequence confusions / suffix intrusions				
Low Trait Cognitive Anxiety	.03 (.06)	.03 (.05)	.02 (.05)	.04 (.05)
Moderate Trait Cognitive Anxiety	.03 (.05)	.03 (.07)	.02 (.04)	.03 (.05)
High Trait Cognitive Anxiety	.03 (.05)	.02 (.04)	.02 (.05)	.02 (.04)
Memory set intrusions / suffix intrusions				
Low Trait Cognitive Anxiety	.03 (.06)	.05 (.06)	.02 (.04)	.02 (.04)
Moderate Trait Cognitive Anxiety	.02 (.04)	.03 (.08)	.00 (.00)	.02 (.04)
High Trait Cognitive Anxiety	.03 (.05)	.01 (.02)	.01 (.03)	.03 (.06)

5.4.5 Exploratory analyses

Trait somatic anxiety: To assess the specificity of effects to the cognitive dimension of trait anxiety, the main ANOVAs were conducted again, starting with the 4-way ANOVA to assess the effect of memory cue type on performance, but with the groups created according to trait somatic anxiety scores (see Table 5.1). Here, there was a significant interaction between cue type, anxiety group, suffix presentation, and serial position, $F(12, 408) = 2.05$, $MSE = .046$, $p = .020$, $n^2_p = .06$. Therefore, data for colour cues and shape cues were again analysed separately. However, when doing so, this revealed only the same significant main effects of suffix presentation and serial position observed in the trait cognitive analyses, both $p < .001$, with no additional effects observed when considering colour or shape cue trials separately (all $p > .08$). Separating data by serial position, however, indicated that the three-way interaction between cue type, anxiety group, and suffix condition was significant at serial position 2, $F(12, 408) = 2.05$, $MSE = .046$, $p = .020$, $n^2_p = .06$, $BF = 1.18$, position 3, $F(4, 136) = 2.94$, $MSE = .040$, $p = .023$, $n^2_p = .08$, $BF = 1.26$ and position 4, $F(4, 136) = 2.69$, $MSE = .034$, $p = .034$, $n^2_p = .07$, $BF = 0.64$ but not at serial position 1 ($p = .35$, $BF = 0.11$). However, note that in each case there was no support for these interaction from the Bayesian analyses.

To follow-up these interactions, 3 (anxiety group) x 3 (suffix condition) ANOVAs were then conducted within each cue type at serial positions 2-4. At serial position 2, there was a significant anxiety group x suffix condition interaction when colour cues were presented, $F(4, 136) = 2.52$, $MSE = .043$, $p = .044$, $n^2_p = .07$, $BF = 1.50$, but not shape cues ($p = .82$, $BF = 0.06$). Again, this interaction was not supported by the Bayesian analysis. The two-way interaction was not significant at any serial positions 3 and 4 for either colour or shape cues (all $p > .08$, all $BF < 0.89$), following the lack of support for these interactions observed in the Bayesian analyses for the three-way ANOVAs.

To follow-up the anxiety group x suffix condition for colour cues at serial position two, one-way ANOVAs comparing performance across suffix conditions were conducted within each anxiety group. In the low trait somatic anxiety group, the effect of suffix condition was not significant, $F(2, 42) = .02$, $MSE = .031$, $p = .981$, $n^2_p = .001$, $BF = 0.13$. In the moderate group, the effect again was not significant $F(2, 36) = 2.75$, $MSE = .056$, $p = .077$, $n^2_p = .13$, $BF = 1.60$. However, in the high trait somatic anxiety group, the main effect of suffix was significant $F(1.59, 46.18) = 5.23$, $MSE =$

.055, p = .014, n^2_p = .15, BF = 7.23. Bonferroni-corrected pairwise comparisons indicated that performance in the high anxiety group for colour cues at serial position two was significantly worse in the implausible suffix condition (M = .18, SD = .18) than in the control condition (M = 34, SD = .26, p = .009, BF = 7.57) and the plausible suffix condition (M = .32, SD = .24, p = .011, BF = 6.44) with no difference in the plausible and implausible suffix conditions, (p = 1.00, BF = 0.12). Thus the high trait somatic anxiety group appeared to be less able to accurately recall shape features at serial position 2 when presented with an implausible suffix as compared with no suffix or a plausible suffix. Note, there were no significant effects involving trait somatic anxiety across all error data examined (all p > .12, all BF < 0.70).

Multilevel modelling: To explore potential linear effects of anxiety as a predictor of performance, multilevel models were constructed, treating trait cognitive anxiety as a continuous independent variable. Mean-centred trait cognitive anxiety scores, suffix condition, and serial position served as fixed-effects predictors. Terms were entered factorially, at a single level, including each main effect, the two-way interactions, and the three-way interaction. An unstructured repeated covariance structure was selected, in line with multivariate repeated-measures ANOVA (Hoffman & Rovine, 2007). Participant identifier served as a random factor. The full outcomes for tests of fixed effects in the multilevel model analyses can be viewed in Appendix H. For colour memory, as with the ANOVAs reported above, the analysis indicated significant effects of suffix condition, F(2, 68.00) = 7.82, p = .001, and serial position, F(3, 68.00) = 53.50, p < .001. and no other significant effects (all p > .30). For shape memory, there were significant effects of suffix condition, F(2, 68) = 18.69, p < .001, and serial position F(3, 68.00) = 36.79, p < .001, and no other significant effects (all p

> .32). The same pattern was observed when examining trait somatic anxiety.

5.5 Discussion

Study 2 was conducted with the aim of determining whether higher levels of trait cognitive anxiety were associated with a binding deficit in visual working memory, and whether this potential deficit was influenced by the presentation of to-be-ignored, task-irrelevant visual stimuli ('suffixes'). These suffixes varied according to plausibility, being either suffixes that were made up of features from the set of potential memory features (plausible suffixes), or novel features that were never part of the memory arrays (implausible suffixes). It was expected that individuals reporting relatively high levels of trait anxiety would see a greater degree of suffix interference than those reporting lower levels and would see a greater drop in recall performance in the final item in the memory sequence specifically. The results provided no evidence that higher levels of trait anxiety negatively impact on sequential visual feature binding. They also suggest that anxiety does not interact with suffix presentation in determining visual feature binding performance.

5.5.1 Anxiety and visual working memory for sequentially presented stimuli

As with the results of Study 1, in the present study there was no evidence of a binding deficit at higher levels of trait anxiety (measured via either the cognitive or somatic dimensions). Potential reasons for this, with respect to serial position data, were provided in the discussion for Study 1 (Chapter 4, Section 4.5.2). However, it is worth reiterating the specific implications of the lack of relationship between anxiety and performance on binding tasks. Although Eysenck et al. (2007) assumed that anxiety reduces top-down control of attention, it appears that anxiety does not simply serve as an additional executive load that disrupts performance effectiveness. Anxiety serving as an additional load was expected to have manifest as a greater reduction in early-sequence performance for the high anxiety group compared to the other groups.

The properties of the visual binding task should also be considered with respect to Eysenck et al.'s (2007) predictions that anxiety affects attentional inhibition and shifting more so than working memory updating. As discussed in Section 4.5.2, a lack of an observed relationship between anxiety and performance would also suggest that for sequential arrays does not rely on attentional inhibition and switching to the same degree as maintaining or updating working memory representations. The sequential binding task requires encoding and maintaining new memory representations, and updating the contents of working memory is less reliably associated with deficits arising from anxiety (Berggren & Derakshan, 2013; Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011). The present results provide further evidence that anxiety is less reliably associated with working memory updating and do so specifically in the context of visual feature binding, which has seldom been studied in relation to anxiety.

5.5.2 Anxiety and inhibition of distractors

Participants who reported higher trait cognitive anxiety did not exhibit a greater reduction in performance when memory arrays were followed by a suffix. Furthermore, they did not make greater suffix errors, that is, errors that indicate the suffix occupied their focus of attention. This was across both the plausible and implausible suffix conditions. This may be related to the memory load used in the present task. Qi, Ding, et al. (2014) found that late contralateral delay activity (CDA) amplitudes – which increase as the number of representations held in working memory increase – in a high trait anxiety group were similar across a distractor condition (two targets and two distractors) and high load condition (four targets). CDA amplitudes in each of these conditions were both being significantly higher than in a low load condition (two targets). By comparison, in a low trait anxiety group, the high load condition was associated with significantly higher CDA amplitudes than the distractor condition, which were in turn significantly higher than the low load condition. This would suggest that high trait anxiety is associated with poorer filtering of stimuli (as two relevant plus two irrelevant items resulted in similar amplitudes as four relevant items). Other neural evidence suggests that high trait anxiety may be associated with a memory capacity of around three items, and low trait anxiety with a capacity of four items (Qi, Chen, et al., 2014). In the present study we used memory sequences of four objects, with the distractor conditions introducing a further object in the task. It is possible that the four-item sequences used here presented too high a memory load for significant effects of distraction to emerge that varied between the anxiety groups, as all groups would have been operating at the capacity of their working memory prior to the introduction of the distractor. It was reasonable to expect that it would still be possible to observe effects of anxiety on performance in the chosen tasks, as attentional manipulations have previously affected performance in this context (e.g. Hu et al., 2014, 2016). However, the present result suggest that participants of varying anxiety levels are similarly affected by four-item loads in working memory. The possibility that load affected performance is addressed in Studies 3 and 4, reported in Chapters 6 and 7.

It should however be noted that there was some evidence for an effect of trait somatic anxiety on performance. Specifically, when colour cues were presented, and participants had to recall a shape feature, the high anxiety group showed selectively reduced performance. The high trait somatic anxiety group exhibited reduced performance at serial position 2, specifically when implausible suffixes were presented. This may suggest that presentation of these suffixes interfered with these participants' executive control of attention. That is, they experienced greater difficulty maintaining an item in the face of interference from subsequent items, and subsequently recalling the correct feature at test. However, further research is required in this context, particularly owing to the ambiguity surrounding implausible suffix responses detailed in Section 5.3.2. Indeed, given that plausible suffixes did not significantly reduce performance for this group at this serial position and for this cue type, it may be the case that participants in the high trait somatic anxiety group showed a deficit because of this ambiguity (i.e. had greater difficulty differentiating memory array features from suffix features). An important point to note is that Bayesian analyses did not provide strong support for the significant frequentist outcome, suggesting that the observed effect may have been spurious. Nonetheless, targeted studies focusing on the relative memory for shape and colour cues under varying suffix presentation conditions (e.g. plausible, implausible, and control conditions) and better differentiating implausible suffix features from those in the memory array, would help to clarify the extent to which this effect is reliable.

5.5.3 Suffix interference in sequential feature binding

The present findings are inconsistent with relatively stable suffix interference effects observed across previous research. Previous studies have shown that presentation of a visual suffix significantly reduces memory for the final object in a memory sequence to a greater extent than other items (e.g. Hu et al., 2014, 2016). This effect was not observed in the current study, with suffix presentation reducing performance across the memory array. Furthermore, based on previous evidence, suffix interference should be increased when the suffix consists of plausible features as opposed to implausible (e.g. Ueno et al., 2011). Here, the degree of suffix interference was similar for both types of suffix. Given the similar degree of suffix interference, and the fact that suffix interference did not selectively reduce memory for the final item in the sequence, but overall memory, it is possible that the suffix simply added to the overall memory load for participants. The lack of an interaction in between suffix condition and serial position suggests that this did not occur as a result of the suffix being processed to a greater extent, to the detriment of recall of the memory array, but by increasing the overall number of objects that were processed in some capacity. The main conclusion that can be drawn from the present results, then, is that increased memory load at the perceptual level, either from irrelevant or relevant stimuli, reduces sequential feature binding performance generally rather than selectively, pointing to a working memory capacity that is limited to less than five items.

5.5.4 Limitations

A particular limitation of this study, as in Study 1, was the use of cued recall responses.

This method of response was adopted to in order to evaluate response error data, which are beneficial for determining the type of confusion or interference that occurs when participants make response errors. However, cued recall did not allow for the measurement of task response times. Measuring response times in a binding study would potentially be beneficial in the context of anxiety, as Eysenck et al. (2007) proposed in their Attentional Control Theory that anxiety impacts on performance effectiveness more so than efficiency. Their prediction is generally well supported by results from studies of attention rather than working memory (see section 5.2), with the influence of distraction from irrelevant stimuli in anxiety having typically been observed in longer response and saccade latencies. With these effects of anxiety on attention in mind, it is possible that effects of suffix interference went undetected in the present study due to the focus on response accuracy as the primary outcome measure. As suggested in Chapter 4, Section 4.5.3, studies examining the effect of anxiety on working memory have typically used change detection or single probe responses in working memory tasks (e.g. Jaiswal et al., 2018; Moreno, 2015; Spalding et al., 2021). Not only might anxiety influence binding task response times more so than accuracy, but the change detection method may also prove more sensitive for detecting effects of anxiety on performance accuracy. Logie et al. (2009) have suggested that cued recall requires both recognition of a memory cue but also memory for the correct verbal response at test. Indeed, there is evidence that recall occurs either as explicit recollection or familiarity responses, and the former is more susceptible to attentional interference (Jacoby, 1999; Symansky & MacLeod, 1996). Therefore, if the sequential binding task is already attentionally demanding and, additionally, requires a more demanding explicit recollection response, the task may have been particularly difficult for all participants, meaning any anxiety-related effects were masked. Explicit recollection, as opposed to implicit familiarity may also present a less direct measure of attentional processes in visual working memory, than memory itself, as these recollections are by definition less automatic and occur consciously. With further consideration to differences in recall format, it is also possible that any potential effects of anxiety on binding were minimised in the present study due to the effort expended by participants (see Section 2.3.4). Hayes et al. (2009) have shown that category learning was significantly worse at higher levels of anxiety when learning was incidental, thus requiring less effort, but not when learning required intent, and thus greater effort. Thus, if participants must apply effort to name responses rather than make same-different judgements, as was the case in the present study, significant effects of anxiety may not materialise. With anxiety thought to primarily impact on cognitive processes via attention, and potentially under conditions requiring less effortful processing, the use of change detection/single probe recognition responses was pursued in Studies 3 and 4, reported in Chapters 6 and 7.

It is also important to highlight the issue regarding correctly categorising error responses in the implausible suffix condition in this study. Typically, researchers that have used an implausible suffix condition have provided labels for all visual features presented to participants, including the implausible suffixes (e.g. Ueno et al., 2011). Such labels allow for responses to be more accurately distinguished as being either from the memory feature set or suffix feature set. However, implausible suffix labels were not presented in this study. Anecdotally, participants did not appear to struggle with responses despite not being presented with the labels, however, the lack of labels made it difficult to correctly categorise error data completely for analyses. It is possible that the proportion of correct responses recorded in the implausible suffix condition were slightly inflated, given that in some trials a participant may have recalled a similar suffix feature to the correct feature response. This is because when participants answered correctly with the label of the cued feature, and the feature was similar to that of the implausible suffix, the response was coded as correct. As such, there remains scope to better understand the relative impacts of plausible and implausible suffixes on performance in the context of anxiety with this greater degree of response categorisation in place. It should be noted though, that the pattern of serial position data was largely similar in the implausible suffix condition as compared to the control and plausible suffix conditions, with no notable unexpected results found. Ultimately, the present results are still useful with regard to comparing the effects of anxiety on binding in a control condition compared to two suffix interference conditions, in that the expected effect of an additional suffix in reducing task performance was observed.

5.6 Chapter summary

The results of Study 2 did not provide any evidence to suggest that trait cognitive or somatic anxiety negatively affect the binding of visual features in working memory. Furthermore, there was no evidence to suggest that participants who reported higher levels of trait anxiety were more susceptible to interference from irrelevant visual stimuli. The present study complemented Study 1 by considering this specific bottom-up manipulation of attention, but there are still means by which the relationship between anxiety and visual working memory can be further clarified. The studies reported thus far suggest that anxiety does not affect cued recall for memory sets of four items, while previous evidence (e.g. Moreno et al., 2015; Qi, Chen et al., 2014;

Spalding et al., 2021) suggests that anxiety affects recognition memory in relation to memory sets of three items. Studies 3 and 4, reported in the following chapters, were designed to further assess whether the use of varying set sizes and single probe recognition memory tests may clarify the extent to which anxiety impacts on visual working memory.

6 Study 3 - Impacts of anxiety on visual working memory as a function of set size and memory type

6.1 Chapter overview

This chapter reports Study 3, in which working memory was tested for both individual features and feature conjunctions (bindings). Specifically, participants' memory was tested for sequences of either three or four coloured shapes, and they were asked to indicate whether a memory probe item (a blank shape or colour-shape combination) had appeared in this initial sequence. In light of a lack of observed effects of anxiety in a cued recall binding task in Studies 1 and 2 (see Chapters 4 & 5), Study 3 included a single probe recognition response method, which may be more sensitive to accuracy and which also allows for the measurement of response times (RT). Participants were again grouped according to their anxiety scores relative to the rest of the sample. Participants were asked to complete a sequential binding task in which memory was tested for either three or four memory items. Performance was also compared across individual feature memory (blank shapes) and bindings (coloured shapes). Results showed that the effects of anxiety on memory performance differed depending on the dimension of anxiety assessed. The moderate and high trait cognitive anxiety groups were significantly more accurate in shape memory performance than binding memory performance. Furthermore, trait cognitive anxiety exhibited a positive linear relationship with, and significantly predicted, shape memory performance. With trait somatic anxiety, the moderate and high anxiety groups were also more accurate in shape memory than binding memory, specifically at set size three. Further to this, when treating trait somatic anxiety as a continuous variable, there was a significant, negative association between anxiety and binding memory across set size. Therefore, higher trait cognitive anxiety may be associated with a facilitation of performance when task conditions within the sequential memory paradigm are less demanding (i.e. there is no need to bind object features), resulting in improved shape memory. By comparison, higher trait somatic anxiety may impair performance when the task requires binding and is therefore more demanding. These results are interpreted in the context of recent studies examining the impact of anxiety and negative emotion on visual working memory.

6.2 Study 3 – Introduction

The experimental methods employed in Studies 1 and 2 (Chapters 4 and 5) of this thesis followed those of recent, key studies in visual feature binding (Hu et al., 2014, 2016). The types of task used in these studies have helped to develop a theory of visual working memory that incorporates the role of executive and perceptual attention. Therefore, it was justified to assess whether anxiety affected performance in this type of task in Studies 1 and 2. However, effects of anxiety on visuospatial working memory have often been observed in studies using change detection and single probe recognition tasks, as opposed to cued recall. For example, Jaiswal et al. (2018) probed orientation-location binding with Luck and Vogel's (1997) change detection paradigm (see Section 3.3.1). Here, a group classified as high in trait anxiety and low in trait mindfulness demonstrated poorer change detection accuracy and less sensitivity to detecting changes than did a group classified as low in trait anxiety and high in trait mindfulness. This suggests that anxiety can negatively influence working memory efficiency and effectiveness, potentially by interacting with other trait factors (in this case, reduced mindfulness, i.e., the ability to focus and regulate attention on a present situation to reduce cognitive and emotional distress; Bishop et al., 2004). Other studies using a similar paradigm have found effects of anxiety on measures of working memory but demonstrated less reliable effects on behavioural outcomes. Qi, Chen, et al. (2014), for example, demonstrated a detrimental effect of anxiety on working memory capacity via contralateral delay activity, a reliable measure of individual differences in working memory capacity, but not performance accuracy. Indeed, other studies have suggested that anxiety may in fact improve working memory capacity, as observed by performance in Luck and Vogel's (1997) change detection task (see Section 3.3.1). Moriya and Sugiura (2012) and Moriya (2018) each found that working memory capacity, operationalised as Pashler's *K,* was positively associated with trait social anxiety. While it does appear that anxiety can be observed to be associated with behavioural measures of working memory, differences in the dimension of anxiety being measured, or procedural differences, may have resulted in the inconsistent pattern of findings.

Although useful in indicating the potential relationship between anxiety and working memory, these studies have not accounted for the potential effects of stimulus complexity (i.e. features compared to bindings) on performance. Moreno et al. (2015) used a change detection method for simultaneously presented arrays of coloured shapes, finding slower performance in high compared to low worriers, regardless of memory type. The results reported by Moreno et al. and Jaiswal et al. (2018) may therefore support the view that effects of anxiety may be more readily observed when participants are required to make a choice in a change detection paradigm, rather than via oral cued recall. Logie et al. (2009) have suggested that cued recall may require not only memory for the cued object, but memory for the correct target label (see Section 4.5.3). Therefore, effects of anxiety may be more likely to emerge in change detection tasks due to reduced demands on memory as compared with cued recall tasks, and effects of reduced attentional control may be more clearly observed.

There is, however, additional value in employing a change detection or probe recognition paradigm. Change detection tasks in which participants are required to indicate via a keypress that they do or do not detect changes in test objects allow for researchers to assess variations in performance efficiency through measurement of response times (RT). More pronounced effects of anxiety on efficiency, compared to effectiveness, is a central prediction of ACT (Eysenck et al., 2007). As discussed in Section 2.4.3, anxiety is associated with slower task RTs (e.g., Moser et al., 2012, Sadeh & Bredemeier, 2011) and saccade latencies (e.g. Ansari et al., 2008; Ansari & Derakshan, 2010) and lower efficiency as operationalised as a ratio of accuracy to correct RT (e.g. Edwards et al., 2015; Edwards et al., 2017). Therefore, it is important to progress to assessing effects of anxiety on visual feature binding through efficiency outcomes, in addition to effectiveness. The value of using change detection and probe recognition is demonstrated by Spalding et al. (2021), who found that both trait cognitive and somatic anxiety predicted slower visual working memory task RTs, specifically in trials in which participants responded correctly. This was the case for both shape and binding memory. Furthermore, participants reporting high trait somatic anxiety had less effective (accurate) binding memory performance. There was also an interaction, in which those reporting high trait somatic anxiety exhibited less effective binding during high levels of state cognitive anxiety. Importantly, Spalding et al.

(2021) tested participants' memory for three items per trial, as opposed to four items as was tested in Studies 1 and 2 of this thesis (see Chapters 4 and 5). In order to further explain lack of observed effects of anxiety on performance in the results reported in Studies 1 and 2, it was important to consider these methodological differences in designing the present study.

Study 3 was therefore designed to assess the impact of anxiety in a sequential visual feature binding task in which responses were based on probe recognition rather than cued recall. Effects of anxiety on recall efficiency have been observed across the type of stimuli participants are asked to remember – either individual features or combinations of features, i.e., bindings – in change detection and probe recognition tasks (Moreno et al., 2015; Spalding et al., 2021). Effects of anxiety on recall effectiveness in this context have been observed specifically for feature binding memory (Spalding et al., 2021). Furthermore, effects of anxiety on change detection have been demonstrated in binding tasks in which participants were asked to remember arrays of three items specifically (Moreno et al., 2015; Spalding et al., 2021). As no effects of anxiety on performance were found using four-item arrays in Studies 1 and 2, it is necessary now to incorporate investigations of set size. As outlined earlier, the capacity of working memory is suggested to be around three to four discrete chunks of information (e.g. Cowan, 2010; Section 1.2.3). This is further supported by Qi, Chen, et al. (2014) who found that participants with high trait anxiety reached the upper limit of memory representation (measured via CDA amplitude) at a memory load of three items, but a low trait anxiety group reached this limit at a memory load of four items. Therefore, effects of anxiety may have been masked due to the four-item arrays/cued recall method imposing a memory load resulting in near-floor level performance across all anxiety groups. Further investigating the effects of set size on performance is particularly important given that Attentional Control Theory (Eysenck et al., 2007; see also Berggren & Derakshan, 2013; Derakshan & Eysenck, 2011) does not make specific predictions regarding the capacity limitations of working memory arising from high levels of anxiety. While a general capacity deficit is assumed, it is important to develop further on Qi, Chen, et al.'s (2014) findings in a behavioural context. If anxiety deficits appear as a function of set size, this would indicate that anxiety is associated to some extent with working memory capacity. This finding would have implications for the understanding of visual working memory more generally, with respect to the effects of internally driven distraction and the interaction with external task demands.

6.2.1 Hypotheses

The present study adopted a sequential binding task in which participants' recognition memory was tested for features (blank shapes) or bindings (coloured shapes). Memory was tested across set sizes of three or four items. Participants were again grouped according to trait anxiety levels (low, moderate, or high). Based on the results of Spalding et al. (2021; Study 2) and those reported in the present Studies 1 and 2 (see Chapters 4 and 5) a three-way interaction was predicted for both performance efficiency and performance effectiveness. Specifically, all groups were expected to show a binding deficit in both set sizes. However, this was expected to be greatest in the high trait cognitive anxiety group at set size three, due to an association between anxiety and reduced working memory capacity.

6.3 Study 3 – Method

This study was preregistered with the Open Science Framework prior to data collection. The pre-registration for the study can be found at https://osf.io/2scf4, with underlying data to be made available following publication.

6.3.1 Participants

Participants were 86 young adults (28 male, 58 female) aged 17-32 years (*M* = 21.82, *SD* = 2.83). Their mean years of education was 15.41 (*SD* = 2.05)[7]. Participants were recruited from the undergraduate participant pool for Psychology at the University of Strathclyde, and via opportunity sampling. All participants reported normal/corrected-to-normal vision, and no memory impairments. Note, the original target sample size was 96. However, due to sudden COVID-19-related lab closures, the study had to be terminated slightly earlier than planned. A power analysis conducted using MorePower 6.0 (Campbell & Thompson, 2012) indicated that the initial target sample size of 96 would have been sufficient to detect a moderate-to-large effect (n^2_p = .10), for the three-way interaction or main effect of anxiety, α = .05, power = .80. A retrospective power analysis indicated that the final sample size of 86 was sufficient to detect a moderate-to-large effect (n^2_p = .11) for a three-way interaction or main effect of anxiety, α = .05, power = .80.

[7] Note, one participant did not provide their years of education.

Table 6.1 Participant demographic data by anxiety group for Study 3.

	N	Anxiety Min–Max, *M* (*SD*)	Age *M* (*SD*)	Sex (M:F)	Yrs Education *M* (*SD*)
Trait Cognitive	86				
Low	30	10-17, 14.00 (2.13)	22.47 (3.42)	16:14	15.05 (2.14)*
Moderate	32	18-23, 20.41 (1.62)	22.06 (2.61)	9:23	15.94 (2.02)
High	24	24-34, 27.08 (2.18)	20.75 (1.94)	3:21	15.25 (1.92)
Trait Somatic	86				
Low	26	11-14, 13.12 (0.95)	22.35 (3.60)	10:16	15.34 (2.01)*
Moderate	26	15-18, 16.15 (1.16)	21.38 (2.47)	11:15	16.00 (2.56)
High	34	19-36, 22.26 (3.67)	21.79 (2.45)	7:27	15.57 (3.42)

*Values based on *N*-1

6.3.2 Design

A 3 (anxiety group; low, medium, high) x 2 (set size; three, four) x 2 (memory type; shape, binding) mixed design was used. Anxiety groups were determined according to the criteria detailed in Section 3.4.2. The high anxiety groups consisted of participants reporting levels above a suggested threshold for probable presence of an anxiety disorder (> 23 on the cognitive subscale, > 18 on the somatic subscale; van Dam et al., 2013). The low and moderate groups were determined based on a split of the remaining participants' scores as close to the median as possible. The dependent variables were memory accuracy and memory efficiency (see Section 3.4.2).

6.3.3 Procedure

Task materials were as described in Section 3.4.3. Participants first completed the Trait and then the State versions of the STICSA (Ree et al., 2008), followed by the DASS (Lovibond & Lovibond, 1995). They then completed the binding memory task. Experimental trials were blocked by both set size and memory type instruction, with block order partially counterbalanced across participants. Participants either completed both set size three blocks and then both set size four blocks, or vice-versa, and the order of the memory condition varied within each set size. Therefore, there were four possible orders of administration. The order was counterbalanced across the entire sample. It was not possible to do this within each anxiety group, which were created a posteriori.

At the beginning of each block, participants completed a set of practice trials evenly divided between randomised ‘same’ and ‘different’ trials. ‘Same’ trials were those in which the test probe was originally presented in the memory array, while different trials were those in which the test probe was not presented. ‘Different’ shape probes were taken from the broader pool of memory items while ‘different’ binding probes were new combinations of the colours and shapes originally presented in the memory array, each selected at random (e.g. Allen et al., 2006; Brown et al., 2017). In the ‘same’ trials each serial position was tested once. Thus, in blocks in which the memory set consisted of three items there were six practice trials, and in blocks with a memory set size of four there were eight practice trials. In the experimental trial block, trials were again evenly divided between randomised ‘same’ and ‘different’ trials and, in ‘same’ trials, each serial position was tested an even number of times (six times at set size three and eight times at set size four). Thus there were a total of 36 experimental trials at set size three and 48 trials at set size four. Participants were initially instructed on how to complete the task, then shown an example of a trial and the colour and shape features that could potentially be included in the task. Instructions provided to participants at the beginning of each block can be viewed in Appendix I.

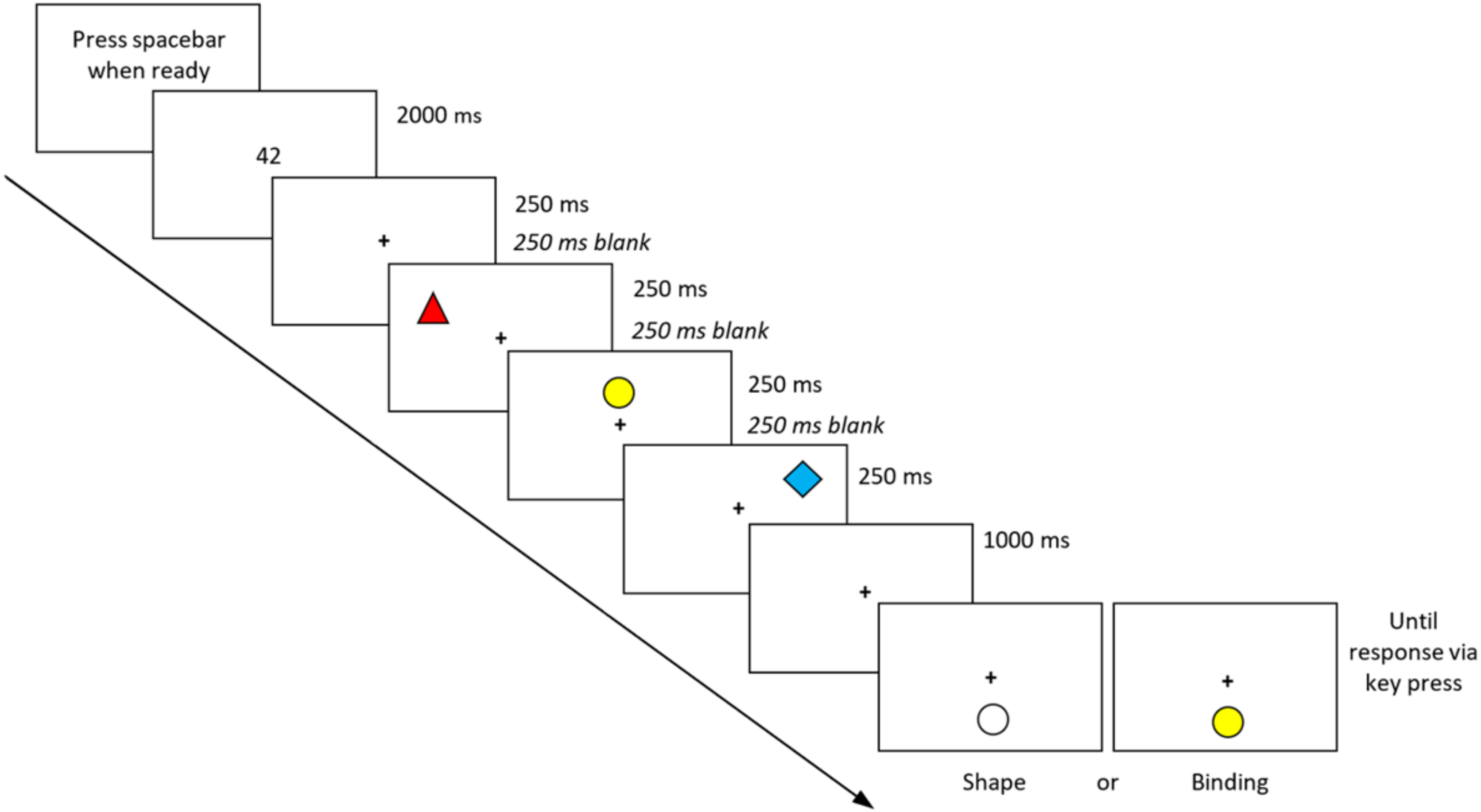

Figure 6.1 An example trial procedure in which the test item (for shape and binding memory test trials) was present in the array. This depicts one trial, in which three memory items are presented sequentially. Stimuli are not drawn to scale.

Participants pressed the spacebar to begin each experimental trial. A fixation cross was shown in the centre of the screen for 500 ms followed by a 500 ms black screen. A two-digit number was then shown for 2000 ms, which the participant immediately began to repeat out loud at a rate of approximately two repetitions per second, in order to suppress subvocal articulation of features. The approximate rate of repetition was demonstrated to participants by the experimenter prior to the task. Repetitions were recorded manually by the experimenter. Following a 250 ms blank screen, each study item was presented for 250 ms, separated by blank screens for 250 ms. Each item was presented in a row just above the centre of the screen, from left to right. A 1000 ms blank screen followed the final sequence item before the test probe was presented at the centre of the bottom half of the screen. Participants indicated whether they thought the test probe had been presented in the initial array by pressing the 'z' key if they thought the item was the same as one presented in the memory array, and the 'm' key if they thought the item was different from those presented in the memory array. Participants were provided with a debrief form and verbally debriefed following the experimental phase.

6.3.4 Data analyses

Analyses followed the general approach detailed in Chapter 3, Section 3.4.2. As change detection responses require a same-different response choice, chance performance level for performance effectiveness data was 50%. Although trait cognitive anxiety was the main variable of interest, as per the OSF preregistration (see Section 6.2.1), it was also necessary to determine whether anxiety dimension influences the findings. Therefore, results are provided for the main analyses focusing on trait cognitive anxiety as well as exploratory analyses focused on trait somatic anxiety. For follow-up tests, Bonferroni corrections were applied automatically in SPSS 27 for pairwise comparisons. Where paired samples t-tests were conducted, the applied correction is noted for that analysis. Bayes factors and exploratory analyses are also reported to complement the results of the main analyses. These include multilevel modelling, which treated trait cognitive and somatic anxiety as continuous variables, and analyses of hit and false alarm data. Hits were classified as correct identification of a change at test, and false alarms as incorrectly reporting a change at test (e.g., Rhodes et al., 2016; see also Stanislaw & Todorov, 1999 for generic approach of signal detection theory). Cohen's *d* was reported to supplement paired differences, calculated in SPSS Version 27 as the standard deviation of the mean difference of the pair.

It should be noted that the measures of performance efficiency reported in Section 6.4.4 vary from those detailed in the initial preregistration. Edwards et al. (e.g., Edwards et al., 2015; Edwards et al., 2016) have highlighted the need to account for the relationship between performance accuracy and RT when considering efficiency and therefore as opposed to operationalizing efficiency as both overall response times and correct response times, it was considered more theoretically relevant to consider correct response times (e.g., Spalding et al., 2021) as well as the following equation (e.g., Edwards et al., 2015; Edwards et al., 2016):

$$Efficiency = \frac{proportion\ correct\ responses}{correct\ RT}\ x\ 1000$$

6.4 Study 3 – Results

6.4.1 Data Checking

One participant provided incomplete data in the trait cognitive subscale of the STICSA and was removed from analyses involving this variable. Another provided incomplete data in the trait somatic subscale and was removed from analyses involving this variable.

6.4.2 Articulatory suppression

Separate 3 (trait anxiety group; low, moderate, high) x 2 (set size; three, four) x 2 (memory type; shape, binding) mixed ANOVAs were conducted, including trait cognitive and somatic anxiety groups, to assess whether the independent variables affected repetition of the two-digit number during the task. Repetition did not significantly vary between groups or conditions in analyses involving either trait cognitive or somatic anxiety, suggesting consistency in performance of this task across participants and task versions (all $p > .09$). The mean number of repetitions are shown in Table 6.2 Mean number of articulations (with SDs) in the concurrent number repetition task across anxiety groups, set size and memory type.

Table 6.2 Mean number of articulations (with *SD*s) in the concurrent number repetition task across anxiety groups, set size and memory type.

	Set Size 3		Set Size 4	
	Shape	**Binding**	**Shape**	**Binding**
Trait Cognitive Anxiety				
Low	5.14 (0.66)	5.17 (0.73)	5.17 (0.69)	5.18 (0.77)
Moderate	5.05 (0.73)	5.12 (0.97)	5.15 (0.79)	5.15 (0.78)
High	5.10 (0.94)	5.21 (1.05)	5.28 (0.91)	5.25 (0.95)
Trait Somatic Anxiety				
Low	5.13 (0.75)	5.27 (0.95)	5.26 (0.83)	5.25 (0.90)
Moderate	4.98 (0.64)	5.00 (0.71)	5.03 (0.55)	5.03 (0.56)
High	5.17 (0.87)	5.17 (0.96)	5.27 (0.90)	5.26 (0.92)

6.4.3 Performance effectiveness

Performance effectiveness data were analysed using a 3 (trait anxiety; low, moderate, high) x 2 (set size; three, four) x 2 (memory type; control, backwards counting) mixed factorial ANOVA (see Appendix J for correlations amongst key variables). [8]

Trait cognitive anxiety. Mean accuracy data can be viewed in Table 6.3. There were significant effects of set size, $F(1, 83) = 80.35$, $MSE = .005$, $p < .001$, $n^2_p = .49$, $BF > 10{,}000$ and memory type, $F(1, 83) = 138.43$, $MSE = .006$, $p < .001$, $n^2_p = .63$, *BF*

[8] Analyses of effectiveness data were also conducted using state cognitive and somatic anxiety scores to form the anxiety groups. In each case there were no significant effects regarding either state anxiety scale (all $p > .06$).

> 10,000. The two-way interaction between set size and memory type was also significant, with moderate support from the Bayesian analysis, $F(2, 83) = 6.79$, $MSE = .006$, $p = .011$, $n^2_p = .08$, $BF = 3.44$. There was also a significant two-way interaction between trait cognitive anxiety group and memory type, $F(2, 83) = 14.57$, $MSE = .006$, $p < .001$, $n^2_p = .26$, $BF > 10{,}000$ (all other $p > .12$, $BF < 0.48$). Multilevel modelling also showed that the two-way interaction between trait cognitive anxiety and memory type was significant, $F(84) = 6.13$, $p = .015$.[9]

Table 6.3 Mean effectiveness data in Study 3 across conditions and trait cognitive anxiety groups.

	Set Size 3		Set Size 4	
	Shape	**Binding**	**Shape**	**Binding**
Trait Cognitive Anxiety				
Low	.73 (.12)	.68 (.10)	.65 (.12)	.63 (.08)
Moderate	.78 (.11)	.65 (.09)	.70 (.09)	.59 (.08)
High	.84 (.08)	.66 (.10)	.73 (.10)	.62 (.09)

Following-up the two-way interaction between set size and memory type, Bonferroni-corrected paired t-tests (to meet significance, *p*-value < .025) indicated that

[9] Including self-reported depression as a covariate did not affect the pattern of significant findings (all non-significant $p > .07$) nor did including stress as a covariate (all non-significant $p > .08$). The pattern of significant findings was also the same when excluding participants who reported currently taking medication for anxiety and/or depression, or those who did not indicate their medication status ($N_{EXCLUDED} = 1$; all non-significant $p > .14$).

shape memory was significantly more accurate than binding memory at both set size three, $t(85) = 8.97$, $p < .001$, $d = 0.96$, $BF > 10{,}000$ ($M_{SHAPE} = .78$, $SD = .11$, $M_{BINDING} = .66$, $SD = .10$) and set size four, $t(85) = 6.00$, $p < .001$, $d = 0.65$, $BF > 10{,}000$ ($M_{SHAPE} = .69$, $SD = .11$, $M_{BINDING} = .61$, $SD = .09$), with the effect being larger at set size three (see Figure 6.2).

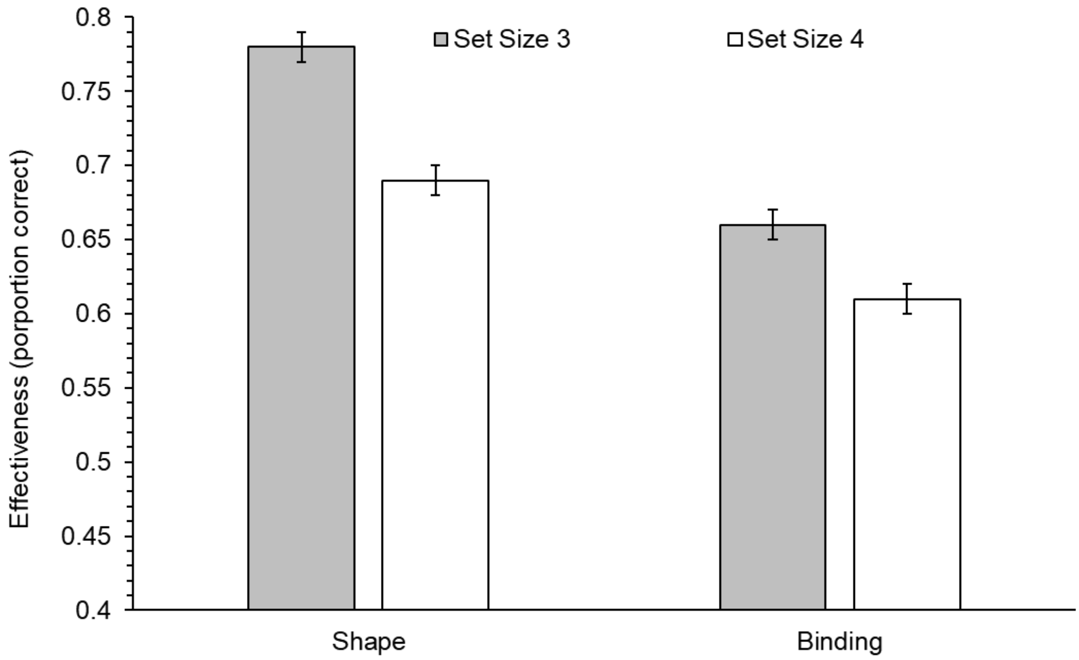

Figure 6.2 Performance effectiveness (± *SE*) as a function of memory type and set size (collapsed across trait cognitive anxiety groups).

To follow-up the interaction between anxiety group and memory type (see Figure 6.3), Bonferroni-corrected paired t-tests (to meet significance, p-value $< .016$), were conducted comparing shape and binding memory within each anxiety group, collapsed across set size. In the low trait cognitive anxiety group, the difference between shape memory (M = .69, SD = .09) and binding memory (M = .66, SD = .07) was not significant, $t(29) = 2.48$, $p = .019$, $d = .45$, $BF = 2.59$. In the moderate group, there was a significant difference between shape memory (M = .74, SD = .09) and binding memory (M = .62, SD = .07), $t(31) = 9.54$, $p < .001$, $d = 1.69$, $BF > 10,000$. In the high group, there was also a significant difference between shape memory (M = .78, SD = .08) and binding memory (M = .64, SD = .09), $t(23) = 8.38$, $p < .001$, d = 1.71, $BF > 10,000$. Effect sizes were similarly large in both the moderate and high anxiety groups.

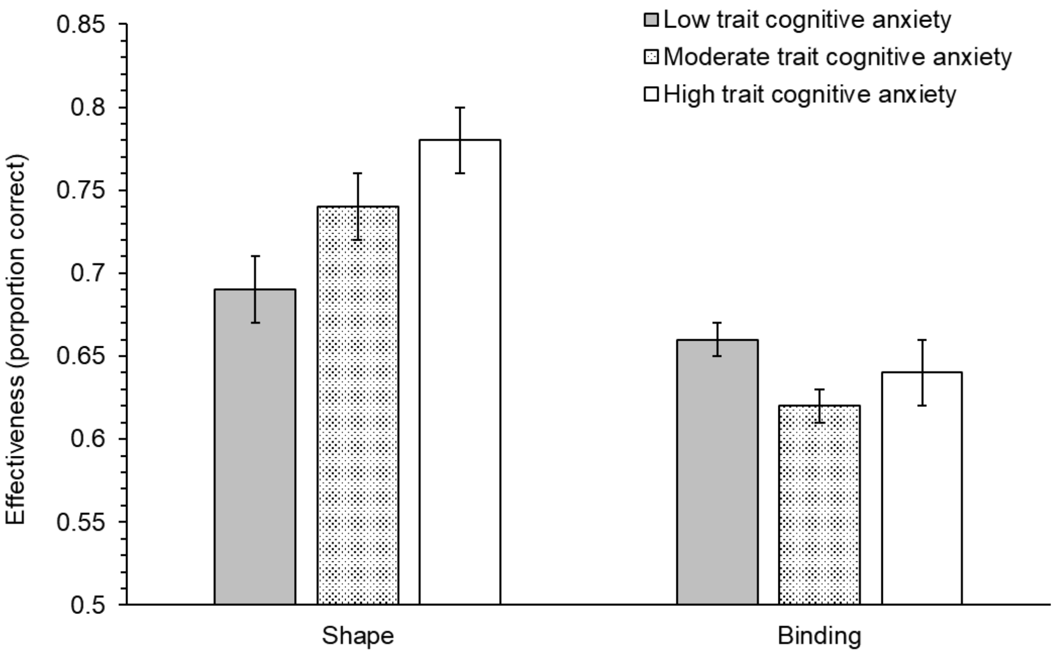

Figure 6.3 Performance effectiveness (± *SE*) as a function of trait cognitive anxiety group and memory type.

The interaction can therefore be explained by the frequentist outcomes and Bayes factors. Shape memory was only significantly better than binding memory in the moderate and high groups – the difference in the low group was not significant once the Bonferroni correction had been applied. The Bayes factors indicated that there was only weak evidence for an effect in the low group, and strong evidence in the moderate and high groups. Results from the MLM (see Appendix K for full fixed-effects outcomes) also showed that the two-way interaction was significant, $F(84) = 29.77$, $p < .001$. Follow-up multilevel modelling of the effect of trait cognitive anxiety within each memory type indicated that trait cognitive anxiety positively and linearly predicted shape memory performance, $F(1, 170) = 17.90$, $b = .006$, CI [.003, .009], $t(170) = 4.23$, $p < .001$, but not binding memory, $F(1, 170) = 1.64$, $p = .202$ (see Figure 6.4).

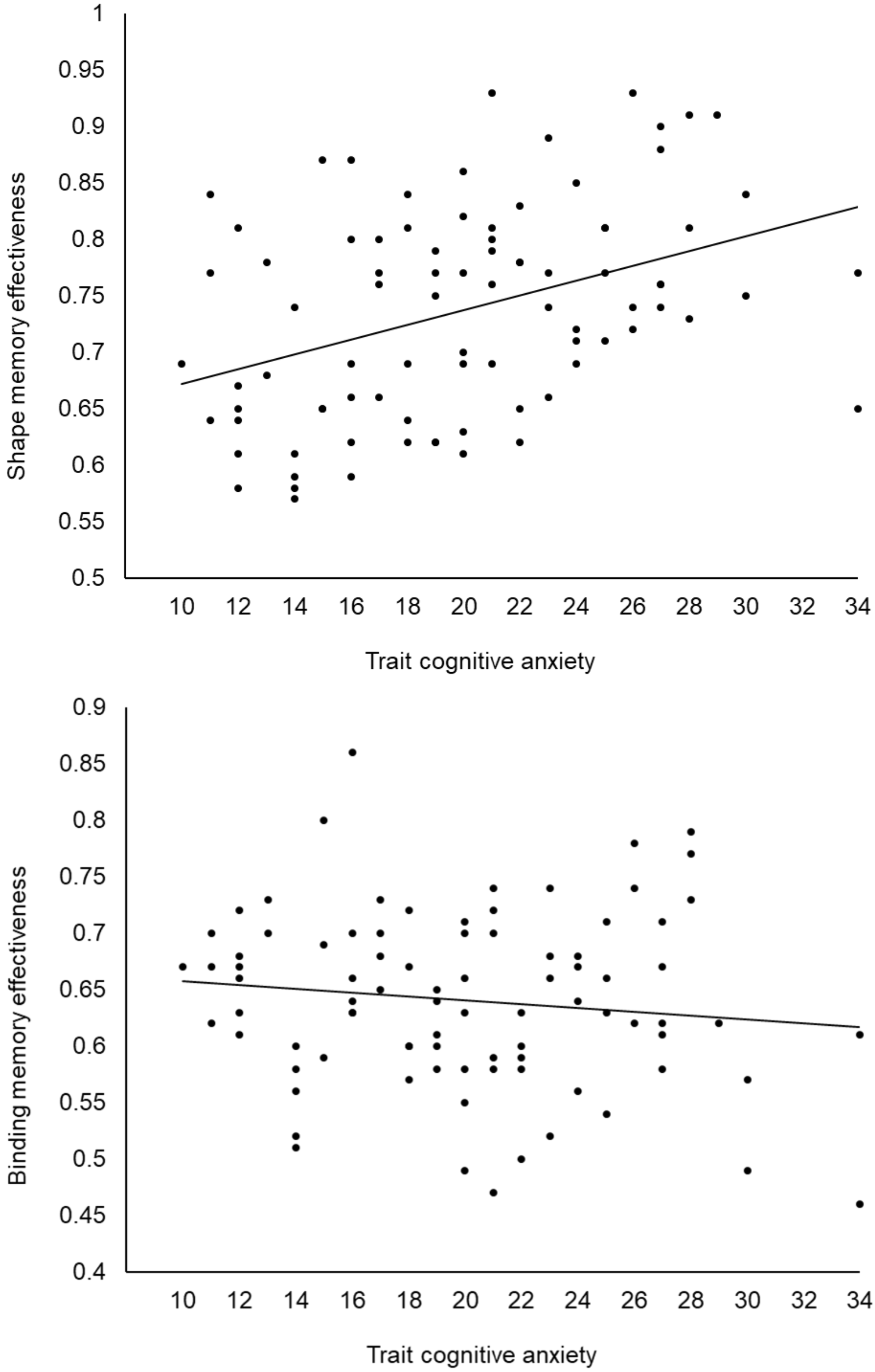

Figure 6.4 Scatterplots demonstrating the significant linear relationship between trait cognitive anxiety and shape memory effectiveness (top) and non-significant relationship between trait cognitive anxiety and binding memory effectiveness (bottom).

Separate 3 (trait cognitive anxiety) x 2 (set size) x 2 (memory type) ANOVAs were also conducted on hit and false alarm rates. Regarding hit rates, the same pattern of main effects was observed, while there was also a significant two-way interaction between anxiety group and memory type specifically for hit rates, $F(2, 83) = 8.14$, $MSE = .022$, $p = .001$, $n^2_p = .16$, $BF = 2992$ (see Figure 6.5).

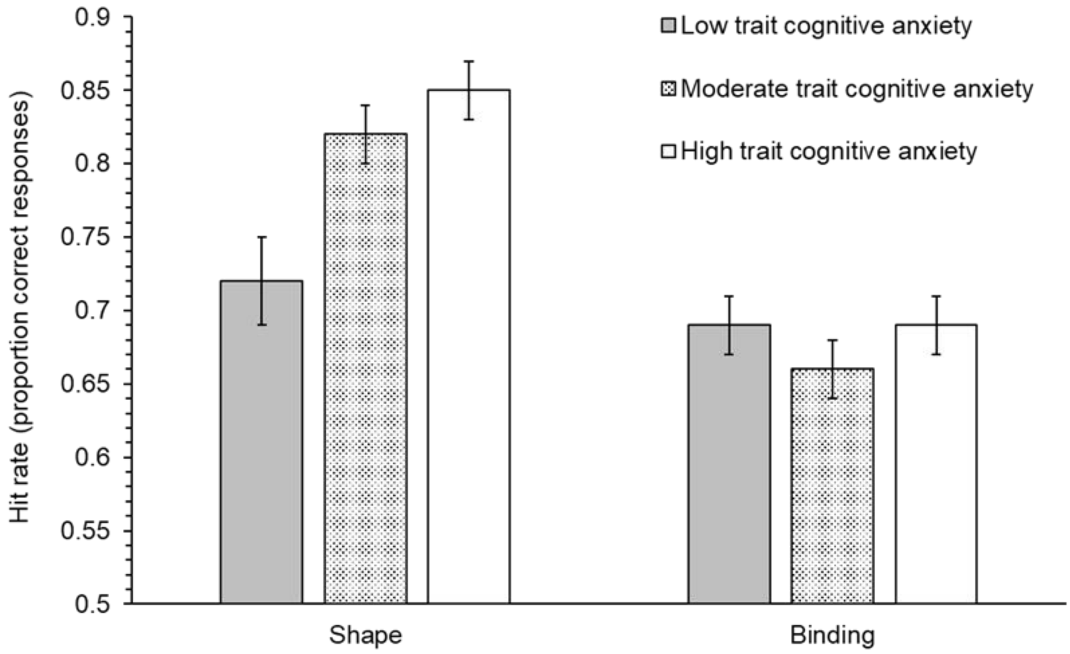

Figure 6.5 Hit rates (i.e., correct identification of change at test; ± *SE*) as a function of trait cognitive anxiety group and memory type.

To follow-up the interaction, Bonferroni-corrected paired t-tests (to meet significance, *p*-value < .016), were conducted comparing shape and binding memory within each anxiety group, collapsed across set size. In the low trait cognitive anxiety group, there was no significant difference between shape memory (*M* = .72, *SD* = .15) and binding memory (*M* = .69, *SD* = .14), $t(29) = 1.05$, $p = .304$, $d = 0.19$, *BF*= .032. In the moderate group, there was a significant difference between shape memory (*M* = .82, *SD* = .12) and binding memory (*M* = .66, *SD* = .14), $t(31) = 5.31$, $p < .001$, $d = 0.94$, *BF* = 2370. In the high group, there was also a significant difference between shape memory (*M* = .85, *SD* = .10) and binding memory (*M* = .69, *SD* = .14), $t(23) = 5.93$, $p < .001$, $d = 1.21$, *BF* = 4216. Thus, the moderate and high trait cognitive anxiety groups were significantly more accurate at detecting changes in shapes from memory array to test than changes in bindings, while the low group did not significantly differ in shape and binding hits. This reflects the same pattern as in overall proportion of correct responses. Regarding false alarms, there were main effects of set size and memory type reflecting the pattern of the accuracy and hit data, and there were no significant effects involving trait anxiety (all $p > .17$, all *BF* < 0.27). Mean hits and false alarm data can be viewed in Table 6.4.

Table 6.4 Hits and false alarms in Study 3 (with *SD*s) across trait cognitive anxiety group, set size, and memory type.

	Set Size 3		Set Size 4	
	Shape	**Binding**	**Shape**	**Binding**
Hits				
Low trait cognitive anxiety	.77 (.15)	.67 (.18)	.67 (.20)	.72 (.12)
Moderate trait cognitive anxiety	.86 (.13)	.64 (.14)	.77 (.14)	.67 (.16)
High trait cognitive anxiety	.89 (.10)	.69 (.15)	.82 (.15)	.68 (.17)
False Alarms				
Low trait cognitive anxiety	.28 (.19)	.30 (.16)	.44 (.10)	.35 (.16)
Moderate trait cognitive anxiety	.29 (.21)	.36 (.15)	.48 (.17)	.37 (.14)
High trait cognitive anxiety	.23 (.14)	.35 (.16)	.43 (.17)	.36 (.15)

Trait somatic anxiety. Regarding the three-way ANOVA including trait somatic anxiety, alongside the main effects of, and interaction between, set size and memory type described above, there was a significant three-way interaction between trait somatic anxiety group, set size, and memory type, $F(2, 83) = 4.51$, $MSE = .006$, $p = .014$, $n^2_p = .10$, $BF = 3.42$, with moderate support from the Bayesian analysis (see Figure 6.6).[10]

[10] Including self-reported depression as a covariate did not affect the pattern of significant findings (all non-significant $p > .11$), nor did including stress as a covariate (all non-significant $p > .12$). The pattern of significant findings was also the same when excluding participants who reported currently taking medication for anxiety and/or depression, or those who did not indicate their medication status ($N_{EXCLUDED} = 1$; all non-significant $p > .11$).

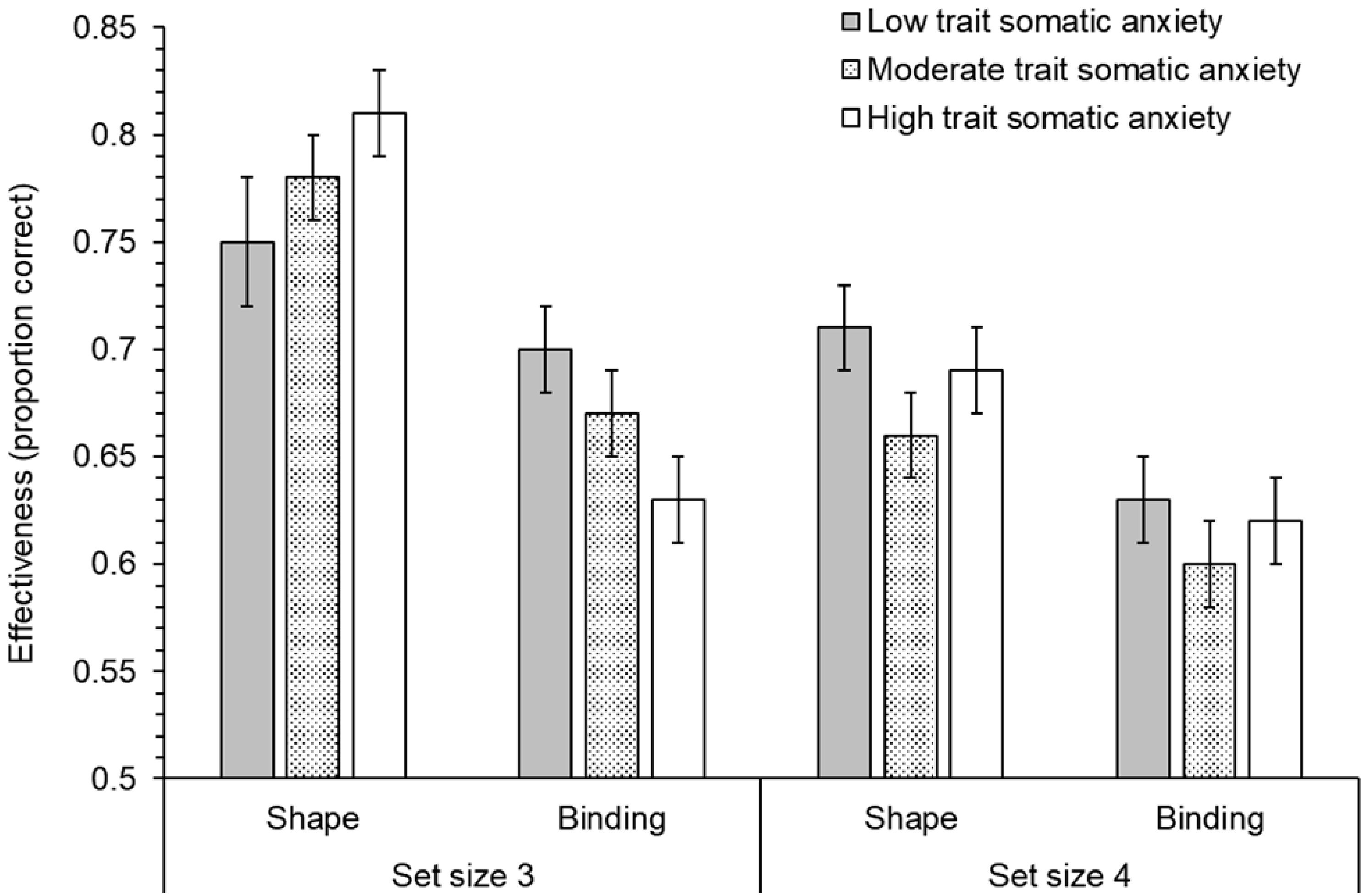

Figure 6.6 Performance effectiveness (proportion correct, ± *SE*) in Study 3 as a function of trait somatic anxiety group, set size, and memory type.

To follow up the three-way interaction, a two-way ANOVA including trait somatic anxiety group and memory type was conducted within each set size. There was a significant interaction between anxiety group and memory type at set size three, $F(2, 83) = 7.62$, $MSE = .007$, $p = .001$, $n^2_p = .16$, $BF = 43.82$, but not at set size four ($p = .748$, $BF = 0.13$). Bonferroni-corrected paired t-tests (to meet significance, p-value $< .016$) were conducted, comparing shape and binding memory within each anxiety group at set size 3. In the low trait somatic anxiety group, there was no significant difference between shape memory ($M = .75$, $SD = .13$) and binding memory ($M = .70$, $SD = .10$), $t(25) = 2.19$, $p = .038$, $d = .43$, $BF = 1.55$. In the moderate group, there was a significant difference between shape memory ($M = .78$, $SD = .10$) and binding memory ($M = .68$, $SD = .08$), $t(25) = 5.81$, $p < .001$, $d = 1.14$, $BF = 4328$. In the high group, there was also a significant difference between shape memory ($M = .81$, $SD = .10$) and binding memory ($M = .63$, $SD = .10$), $t(33) = 8.21$, $p < .001$, $d = 1.41$, $BF >$ 10,000. The interaction can therefore be explained by the frequentist outcomes and Bayes factors. The difference in shape and binding memory was not significant in the low trait somatic anxiety group after applying the Bonferroni correction, and the Bayesian analysis only provided weak support for an effect. However, in the moderate and high groups, the effect was significant and received strong support from the Bayesian analyses. However, multilevel modelling did not indicate that the three-way interaction significantly predicted performance effectiveness, $F(1, 84) = 2.69$, $p = .105$. Instead, the two-way interaction between trait somatic anxiety and memory type was significant in this analysis, $F(1, 84) = 10.71$, $p = .002$. Follow-up multilevel modelling of the effect of trait somatic anxiety within each memory type indicated that trait somatic anxiety was negatively and linearly associated with binding memory, F(1,

170) = 9.27, b = -.005, CI [-.008, -.002], $t(170)$ = -3.05, p = .003, but was not significantly associated with shape memory, $F(1, 170)$ = 1.03, p = .312 (see Figure 6.7).

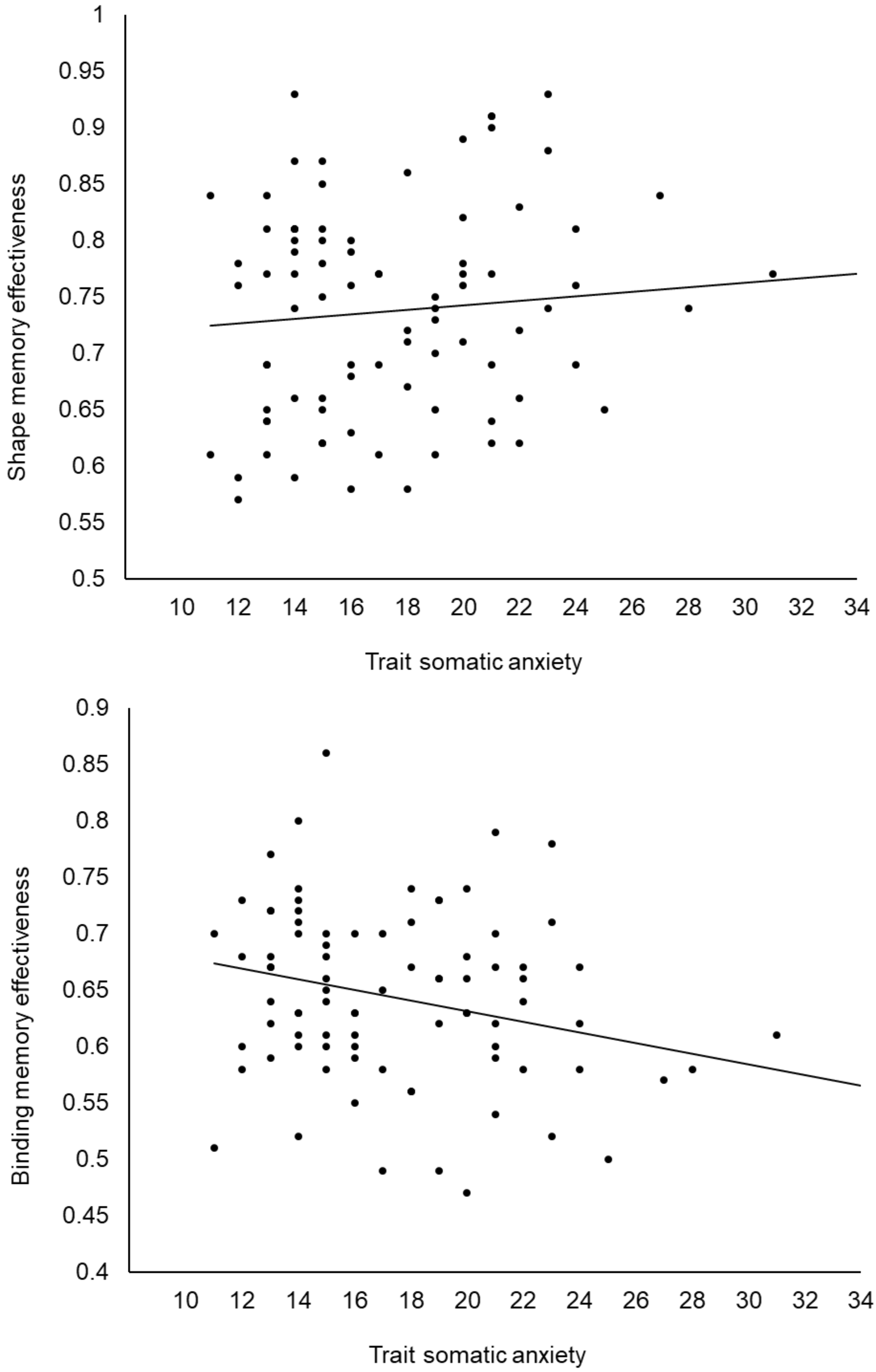

Figure 6.7 Scatterplots demonstrating the non-significant relationship between trait somatic anxiety and shape memory effectiveness (top) and the significant linear relationship between trait somatic anxiety and binding memory effectiveness (bottom).

Hits and false alarm rates were also analysed for trait somatic anxiety. For hit rates, there were no significant main effects or interactions other than the aforementioned main effects of set size and memory type and the interaction between these, referred to in the trait cognitive anxiety analyses (all p > .22 all BF < 0.62). Regarding false alarm rates, however, there was a two-way interaction between anxiety group and memory type, $F(2, 83) = 4.30$, $MSE = .014$, $p = .017$, $n^2_p = .09$, $BF = 2.09$ (see Figure 6.8). However, this result received only weak support from the Bayesian analysis. Bonferroni-corrected paired t-tests (to reach significance, p-value < .016) indicated that the low trait somatic anxiety group made significantly fewer binding false alarms ($M = .31$, $SD = .14$) than shape false alarms ($M = .36$, $SD = .13$), $t(25) = 2.63$, $p = .014$, $d = 0.52$ $BF = 3.50$. There were no significant differences between shape and binding false alarms in the moderate and high trait cognitive anxiety groups (both $p > .15$).

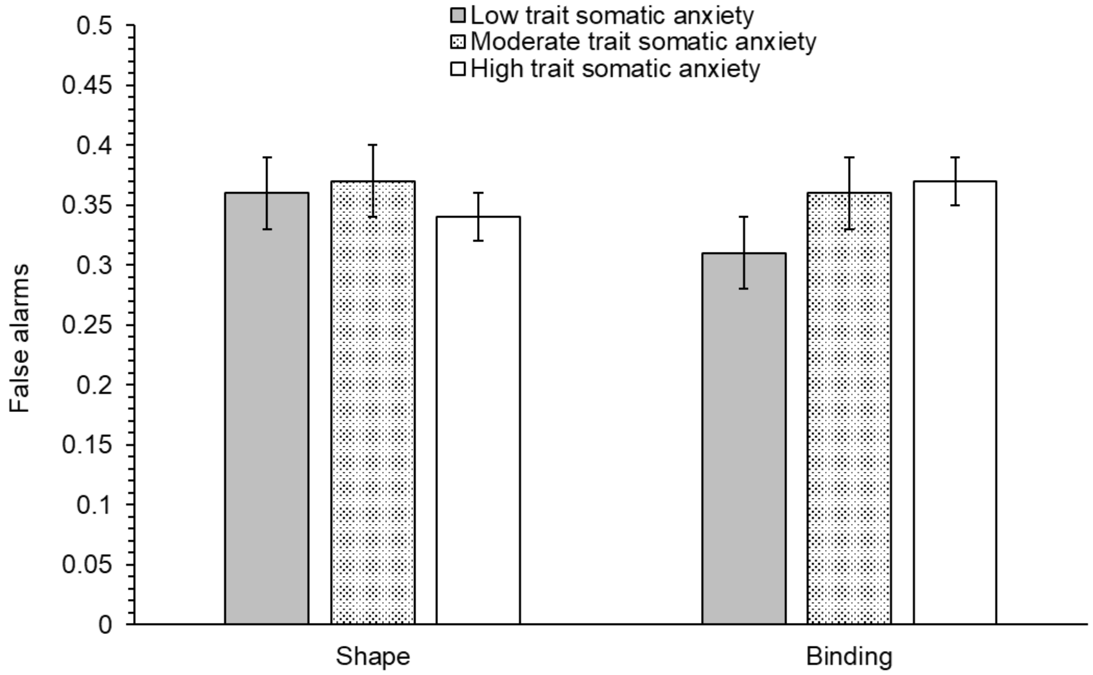

Figure 6.8 False alarm rates, i.e., incorrect report of a change at test (± SE) as a function of trait somatic anxiety group and memory type.

To summarise the performance effectiveness outcomes, there were significant effects involving both trait cognitive and somatic anxiety. There was a significant interaction between trait cognitive anxiety and memory type: the moderate and high trait cognitive anxiety groups, but not the low, were significantly more accurate in shape memory than binding memory. This deficit was driven by better performance in shape memory, as indicated by results from the multilevel analyses. Breaking performance down further, there was also a two-way interaction between trait cognitive anxiety and memory type for hit rates. The high and moderate trait cognitive anxiety groups were significantly more accurate in detecting a change at test (i.e. made more hits) than the low group. When assessing the specificity of these findings to trait cognitive anxiety, a significant three-way interaction between trait somatic anxiety, memory type, and set size was found. The moderate and high trait somatic anxiety groups demonstrated a binding deficit at set size three. The multilevel analyses indicated that this was driven by a reduction in binding memory at higher levels of trait somatic anxiety, rather than better shape memory, as was the case with trait cognitive anxiety. There was also a two-way interaction between trait somatic anxiety and memory type regarding false alarm rates. The low trait somatic anxiety group made significantly fewer binding false alarms than shape false alarms, but there was no difference between memory types for the moderate and high groups.

6.4.4 Performance efficiency

Performance efficiency data were analysed using a 3 (trait anxiety; low, moderate, high) x 2 (set size; three, four) x 2 (memory type; control, backwards counting) mixed factorial ANOVA. [11] [12]

Trait cognitive anxiety. Regarding the key measure of trait cognitive anxiety, there were significant main effects of set size, $F(1, 83) = 21.44$, $MSE = .041$, $p < .001$, $n^2_p = .21$, $BF > 10{,}000$ and memory type, $F(1, 83) = 39.81$, $MSE = .021$, $p < .001$, $n^2_p = .32$, $BF > 10{,}000$. There was also a significant two-way interaction between anxiety group and memory type, $F(2, 83) = 8.13$, $MSE = .021$, $p = .001$, $n^2_p = .16$, $BF = 7.29$

[11] Analyses were also conducted using state cognitive and somatic anxiety scores to form the anxiety groups. There were no effects of state cognitive anxiety (all $p > .11$), but there was a significant main effect of state somatic anxiety ($p = .009$) whereby the high state somatic anxiety group were significantly more efficient than the low ($p = .013$) and moderate ($p = .032$) groups.

[12] Efficiency was also operationalized as correct RT. Using this method, no significant effects were observed on performance (all $p > .054$). Bayesian analysis indicated weak support for an effect of set size on Correct RT ($BF = 2.32$, all other $BF < .043$), but this was not pursued further due to the non-significant frequentist result.

(see Figure 6.9).

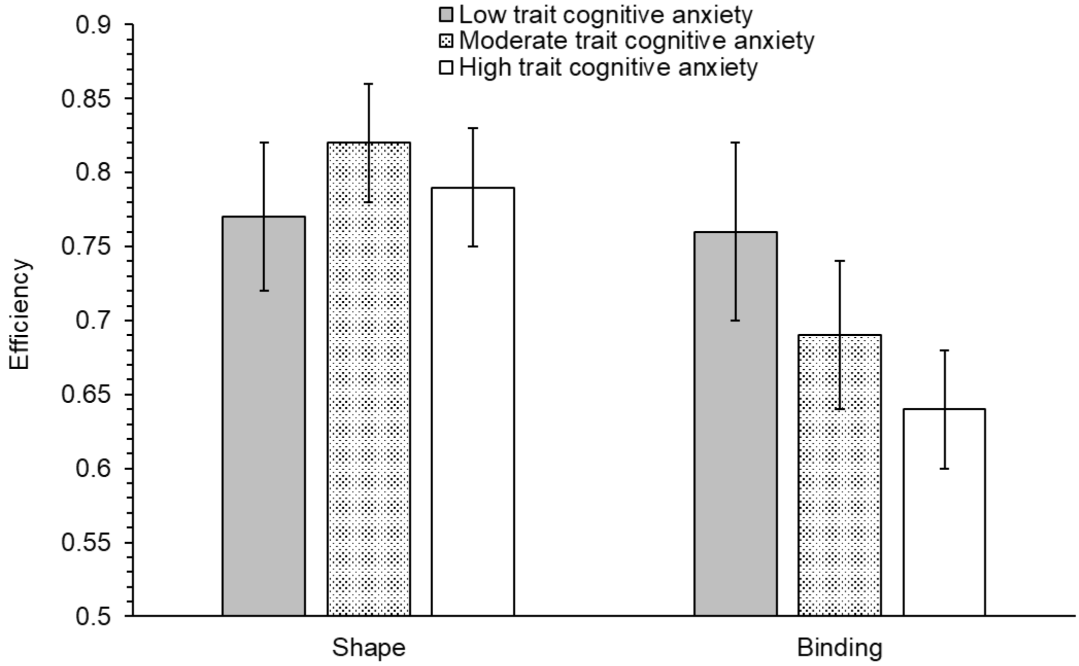

Figure 6.9 Performance efficiency (± *SE*) as a function of trait cognitive anxiety group and memory type.

Bonferroni-corrected paired-samples t-tests comparing shape and binding performance within each anxiety group indicated that, in the moderate group, shape efficiency (*M* = .82, *SD* = .25) was superior to binding efficiency, (*M* = .69, *SD* = .26), *t*(31) = 5.66, *p* < .001, *d* = 1.00, BF = 5823. In the high group, shape efficiency (*M* = .79, *SD* = .19) was again greater than binding efficiency (*M* = .63, *SD* = .19), *t*(23) = 4.66, *p* < .001, *d* = 0.95, *BF* = 249. There was no difference between shape and binding memory in the low group (*p* = .68, *BF* = 0.21). Multilevel modelling also showed the same pattern of findings, including the significant two-way interaction between anxiety group and memory type, $F(1, 84) = 10.01$, $p = .002$.

Trait somatic anxiety. For trait somatic anxiety, alongside the main effects of set size and memory type on efficiency as observed in the trait cognitive analysis, there was a significant three-way interaction between anxiety group, set size, and memory type, $F(2, 83) = 4.24$, $MSE = .027$, $p = .018$, $n^2_p = .09$, $BF = 2.38$, although note this received only weak support from the Bayesian analysis (see Figure 6.10).

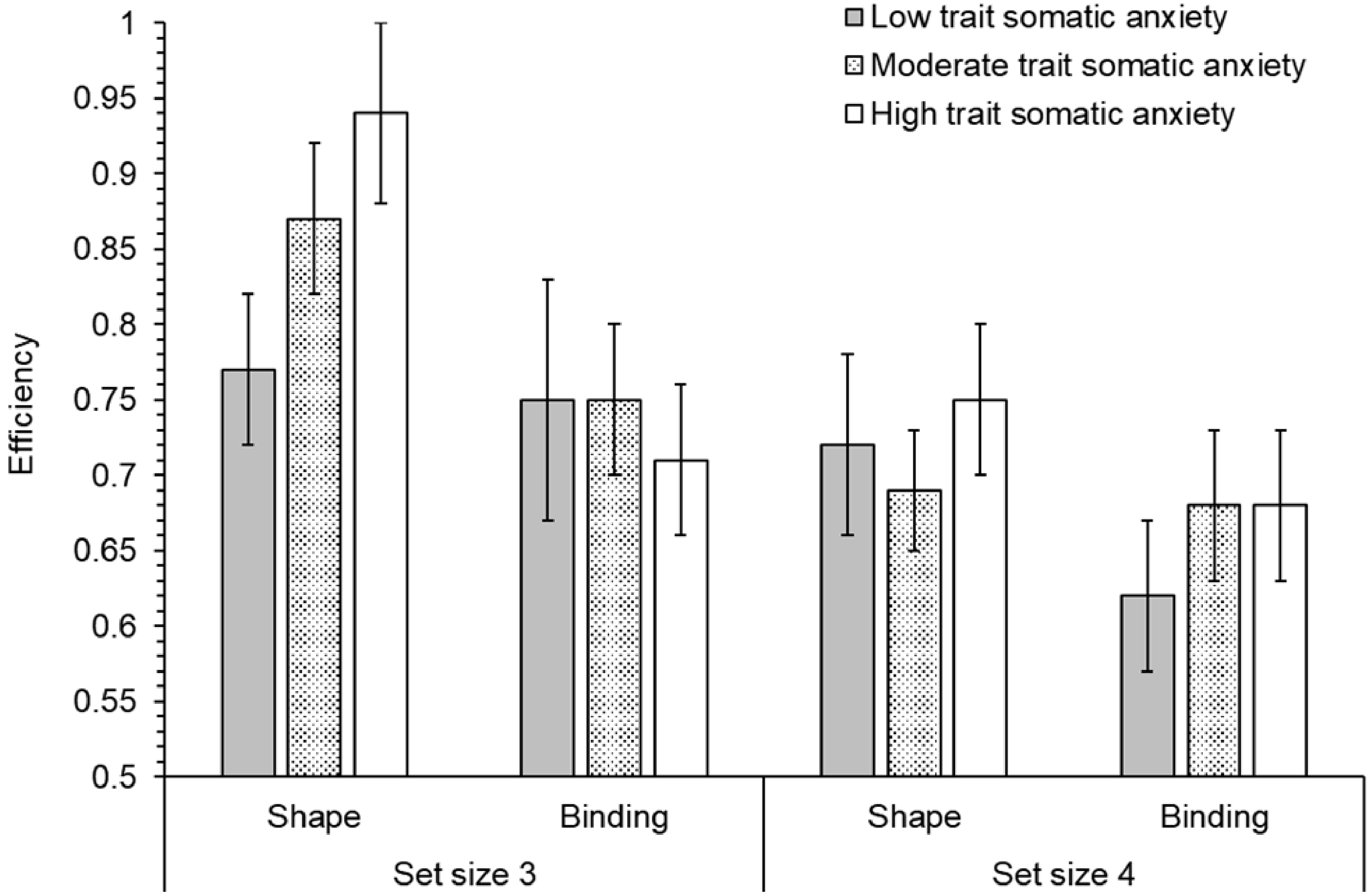

Figure 6.10 Performance efficiency (± *SE*) as a function of trait somatic anxiety group, set size and memory type.

To follow-up this interaction, two-way ANOVAs including trait somatic anxiety group and memory type were conducted within each set size. There was a significant interaction between anxiety group and memory type at set size three, $F(2, 83) = 5.19$, $MSE = .033$, $p = .007$, $n^2_p = .11$, $BF = 46.22$, but not at set size four ($p = .246$, $BF = 0.33$). Bonferroni-corrected paired-samples t-tests (to meet significance, p-value < .016) were conducted to compare shape and binding performance within each anxiety group at set size three. These indicated that, in the moderate group, shape efficiency ($M = .87$, $SD = .26$) was superior to binding efficiency, ($M = .75$, $SD = .23$), $t(25) = 2.62$, $p =.015$, $d = .51$, $BF = 3.39$. In the high group, shape efficiency ($M = .94$, $SD = .32$) was again greater than binding efficiency ($M = .71$, $SD = .31$), $t(33) = 4.63$, $p < .001$, $d = .80$, $BF = 439$. However, in the low group, there was no significant difference between shape memory ($M =.77$, $SD = .28$) and binding memory ($M = .75$, $SD = .39$; $p = .71$, $BF = 0.22$). Thus, there was a significant deficit in binding efficiency in the moderate and high trait cognitive anxiety groups, but not the low group, and the effect was larger in the high group than the moderate group. The three-way interaction was not significant in the context of multilevel modelling, however, $F(1, 84) = 3.24$, $p = .075$.

To summarise the performance efficiency outcomes, as with effectiveness, there were effects relating to both trait cognitive and somatic anxiety. There was a two-way interaction between trait cognitive anxiety group and set size. There was a binding deficit in the moderate and high trait cognitive anxiety groups, but not the low group, driven by enhanced shape memory performance. The three-way interaction between trait somatic anxiety, memory type and set size was also significant. Here, the moderate and high trait somatic anxiety groups, but not the low group, demonstrated a binding deficit in efficiency at set size three, with no other significant differences observed.

6.4.5 Serial position data

Further exploratory analyses were conducted to determine whether effects of anxiety on performance effectiveness were associated with the position in which memory items were presented in the memory sequence. Serial position data are available only for hit rates. Separate trait cognitive anxiety group x memory type x serial position ANOVAs were conducted within each set size. Mean performance effectiveness data in each trait cognitive anxiety group for each memory type at set size 3 can be viewed in Figure 6.11.

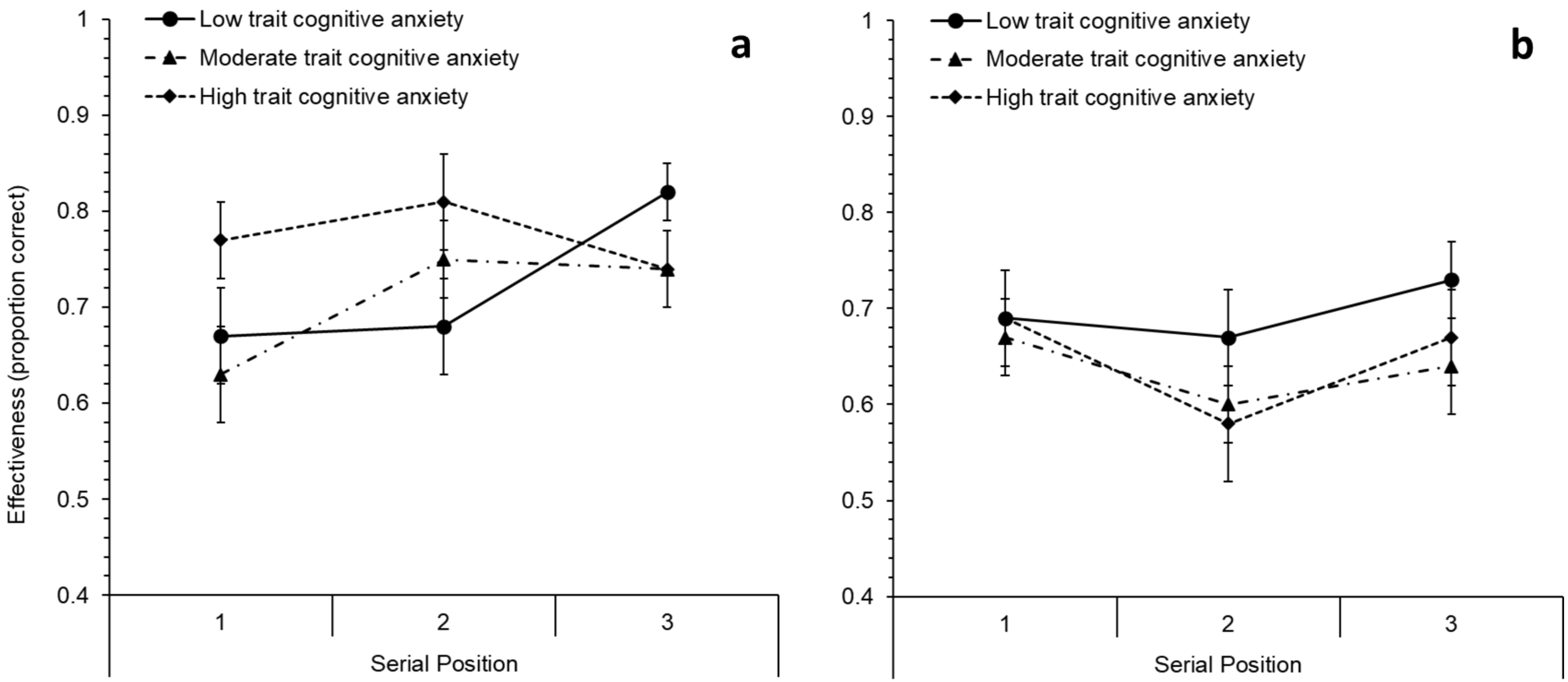

Figure 6.11 Mean **a** shape and **b** binding proportion correct performance (± *SE*) in each trait cognitive anxiety group at set size 3.

Regarding set size three, there was a main effect of memory type $F(1, 83) = 13.19$, $MSE = .055$, $p = <.001$, $n^2_p = .14$, $BF = 69.75$, with shape memory performance significantly greater than binding memory performance. There was also a significant interaction between serial position and memory type, $F(2, 166) = 4.66$, $MSE = .034$, $p = .011$, $n^2_p = .05$, $BF = 0.86$ (see Figure 6.12), although note there was no support for this interaction based on the Bayesian analysis. There were no other significant main effects or interactions (all $p > .09$, all $BF < .21$).

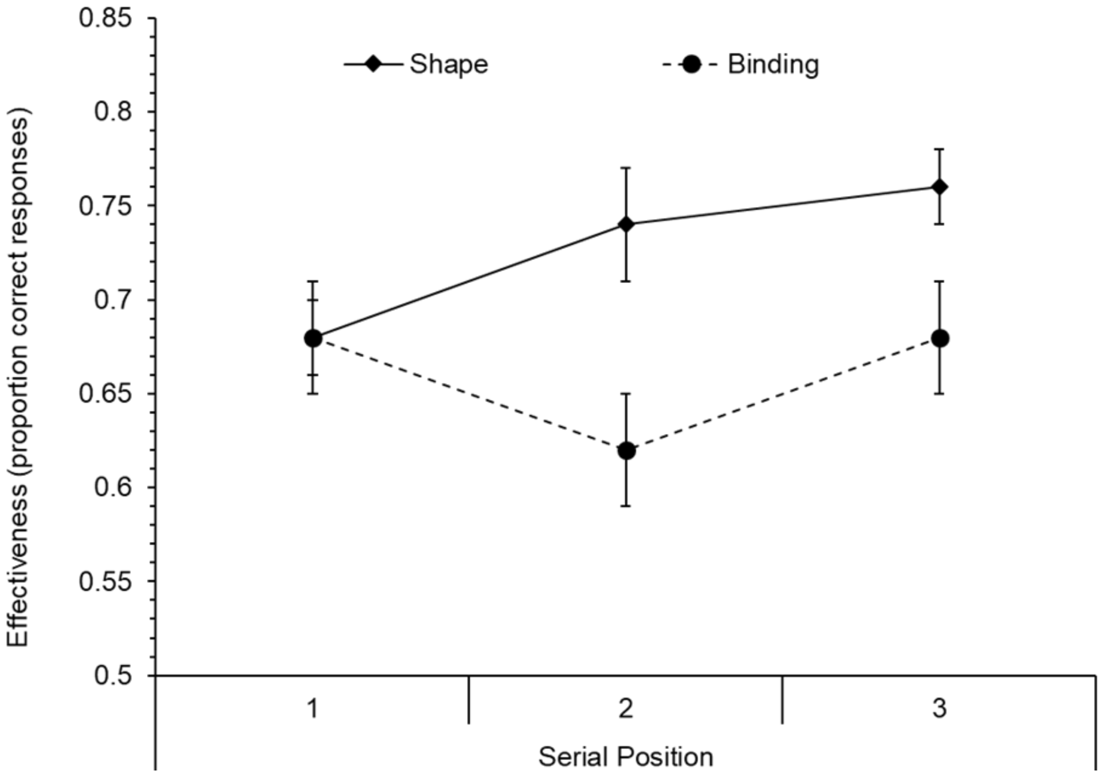

Figure 6.12 Performance effectiveness (± *SE*) for shape and binding memory at each serial position at set size 3.

Following up the interaction between serial position and memory type, repeated-measures ANOVAs conducted within each memory type indicated that the effect of serial position was significant for shape memory, $F(2, 172) = 4.49$, $MSE = .037$, $p = .013$, $n^2_p = .05$, $BF = 2.02$. The effect of serial position was not significant for binding memory, $p = .076$, $BF = 0.24$. Bonferroni-corrected paired t-tests (to meet significance, *p*-value < .016) were then conducted comparing performance at each serial position within shape memory. Performance was significantly lower at position 1 ($M = .68$, $SD = .26$) than at position 3 ($M = .77$, $SD = .20$), $t(85) = 2.78$, $p = .007$, $BF = 4.30$. The difference between positions 1 and 2 ($M = .74$. $SD = .26$) was not significant, $p = .037$, $BF = 1.00$, nor was the difference between positions 2 and 3, $p = .420$, $BF = 0.16$. Note there were no interactions involving both trait somatic anxiety and memory type at set size 3, both $p > .43$.

Regarding set size four, mean performance effectiveness data in each trait cognitive anxiety group for each memory type can be viewed in Figure 6.13.

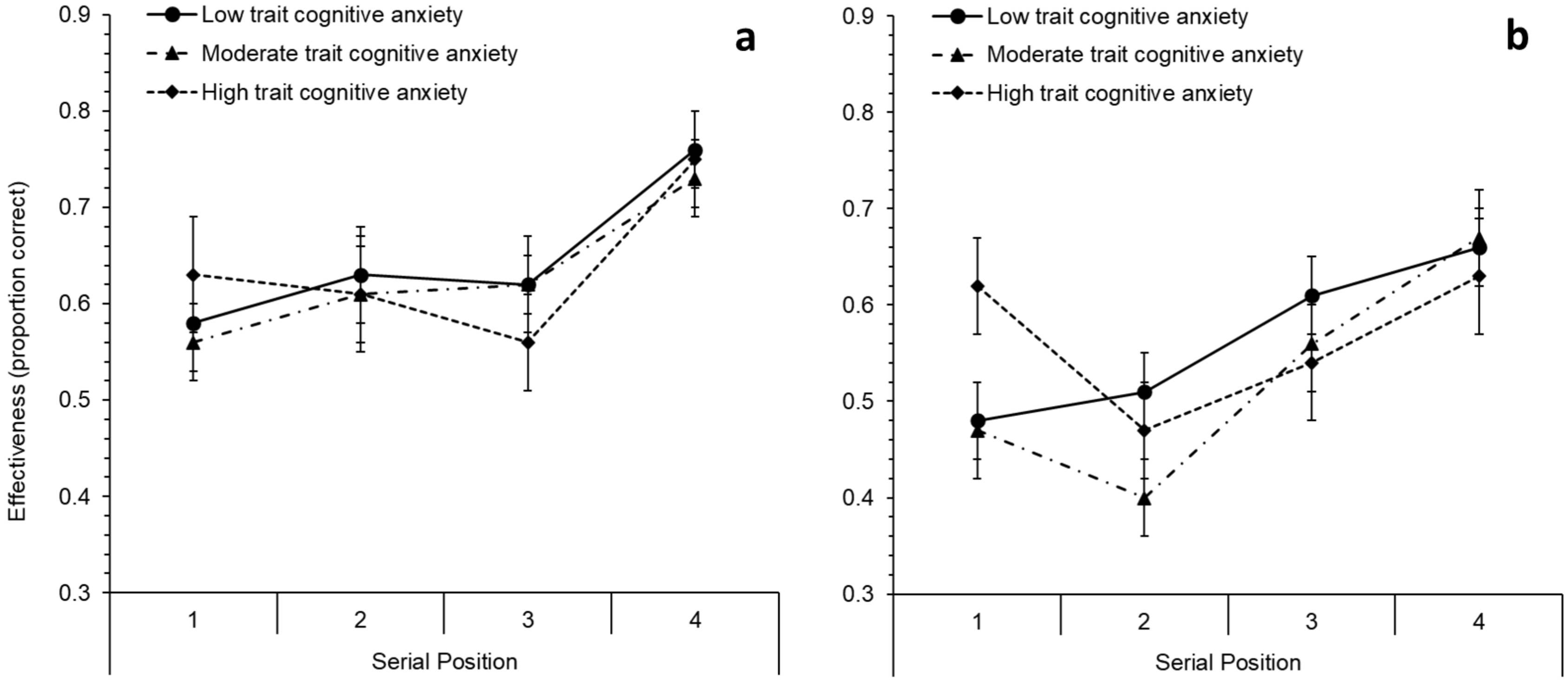

Figure 6.13 Mean **a** shape and **b** binding proportion correct performance (± *SE*) in each trait cognitive anxiety group at set size 4.

There were main effects of both serial position, $F(2.75, 227.89) = 16.19$, $MSE = .065$, p <.001, $n^2_p = .16$, $BF > 10{,}000$, and memory type $F(1, 83) = 8.73$, $MSE = .043$, p <.001, $n^2_p = .10$, $BF > 10{,}000$, however there was also a significant serial position x memory type interaction, $F(2.60, 215.89) = 3.04$, $MSE = .066$, $p = .001$, $n^2_p = .02$, BF > 10,000 (see Figure 6.14). There were no other significant main effects or interactions observed (all $p > .29$, all $BF < .06$).

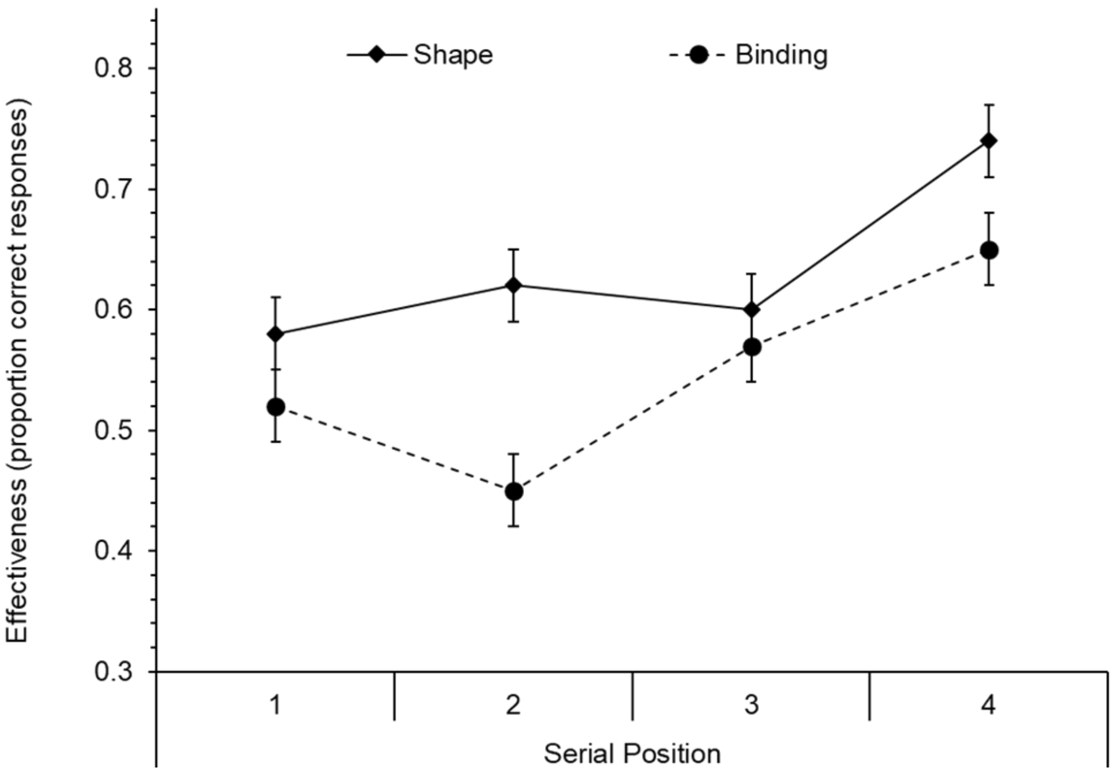

Figure 6.14 Performance effectiveness (± *SE*) for shape and binding memory at each serial position at set size 4.

Following up the interaction between serial position and memory type, repeated-measures ANOVAs conducted within each memory type indicated that the effect of serial position was significant for both shape memory, $F(3, 255) = 8.92$, $MSE = .051$, $p < .001$, $\eta^2_p = .10$, $BF = 1693$, and binding memory, $F(2.96, 251.68) = 10.79$, $MSE = .058$, $p < .001$, $\eta^2_p = .11$, $BF = 22554$. Bonferroni-corrected paired samples t-tests (to meet significance, *p*-value < .008) were then conducted comparing performance at each serial position within each memory type. For shape memory, performance was significantly better at position 4 ($M = .74$, $SD = .23$) than at positions 1 ($M = .58$, $SD = .25$), $t(85) = 4.57$, $p < .001$, $BF = 1036$, 2 ($M = .62$, $SD = .26$), $t(85) = 3.65$, $p < .001$, $BF = 48.78$, and 3 ($M = .60$, $SD = .24$), $t(85) = 4.00$, $p < .001$, $BF = 149.07$, showing a clear recency effect. There were no significant differences between the first three serial positions (all $p > .30$, all $BF < 0.21$). For binding memory, performance was again significantly greater at position 4 ($M = .65$, $SD = .26$) than at positions 1 ($M = .52$, $SD = .26$), $t(85) = 3.58$, $p = .001$, $BF = 38.77$, and 2 ($M = .45$, $SD = .25$), $t(85) = 5.67$, $p < .001$, $BF > 10{,}000$, but not at position 3 ($M = .57$, $SD = .26$), $t(85) = 2.23$, $p = .028$, $BF = 1.29$. Furthermore, performance was significantly poorer at position 2 than at position 3, $t(85) = 3.40$, $p = .001$, $BF = 23.18$. There were no differences between positions 1 and 2 or positions 1 and 3 (both $p > .08$, $BF < 0.53$). Note, there were no interactions involving both trait somatic anxiety and serial position at set size 4, both $p > .52$.

6.5 Study 3 – Discussion

The purpose of Study 3 was to investigate the effects of trait anxiety on visual working memory via a change detection task. The demand of the task was varied in two ways, via manipulation of set size (three or four items) and memory type (shape or binding). As sequential binding is thought to rely on attention, and attentional control is thought to be reduced at higher levels of anxiety (Eysenck et al., 2007), it was expected that individuals reporting high levels of trait cognitive anxiety would demonstrate more impaired binding memory than those reporting lower levels. This was expected to be more easily observed when participants were asked to remember three, rather than four, items in memory, as there is evidence suggesting that highly anxious individuals will reach working memory capacity at three items, while less anxious individuals will reach working memory capacity at four items (Qi et al., 2014). Thus, the high trait cognitive anxiety group were expected to show a greater binding deficit than the other groups at set size three, as the other groups would have had additional capacity to perform better at this set size, before further dropping in performance as the required capacity increased with sets of four items.

The results indicated that the effects of trait anxiety on visual working memory varied somewhat depending on the specific anxiety dimension assessed (either cognitive or somatic). Although higher levels of both trait cognitive and somatic anxiety were associated with better shape memory as compared to binding, the cause of this deficit differed by the anxiety dimension. The moderate and high trait cognitive anxiety groups, but not the low group, showed significantly better performance effectiveness for shape memory compared to binding memory (i.e. the expected binding deficit). Multilevel modelling demonstrated a positive linear relationship between trait cognitive anxiety and shape memory effectiveness, suggesting that increased trait cognitive anxiety improves shape memory. Moderate and high trait cognitive anxiety were also associated with binding deficits in efficiency. By comparison, when considering trait somatic anxiety, the moderate and high trait groups, but not the low group, showed significantly better performance effectiveness for shape memory as compared to binding memory, but only at set size three (i.e., there was a three-way interaction). Moreover, multilevel modelling demonstrated a negative linear relationship between trait somatic anxiety and binding memory effectiveness, suggesting that the three-way interaction was driven by improved shape memory, but also greater binding difficulty at higher levels of trait somatic anxiety. The moderate and high trait somatic anxiety groups, but not the low group, also showed better performance efficiency for shapes than they did for bindings, again at set size three.

Prior to further discussion, however, it should be noted that the observed effects of trait somatic anxiety on both performance effectiveness and efficiency were not well supported by Bayesian analyses. These analyses generally suggested that there was only weak-moderate evidence for the presence of effects of trait somatic anxiety on performance effectiveness, and inconclusive evidence for effects on performance efficiency. As such, findings related to trait somatic anxiety are interpreted below with some caution. In doing so, consideration has also been given to the relative consistency with which a significant effect of trait somatic anxiety on visual working memory has been observed in recent studies that have used a visual feature binding paradigm (see Spalding et al., 2021; the present study; Study 4, reported in Chapter 7). That is, while the strength of findings may be considered relatively weak in isolation, it is important to consider that they are in line with those from a wider body of research. As such, while the Bayesian results can inform the strength of the conclusions that can be made, they should not necessarily supersede the frequentist outcomes, particularly when considering the wider evidence that is available.

6.5.1 Trait anxiety and memory effectiveness

A notable outcome of the present study was clear and distinct effects of both trait cognitive and somatic anxiety on visual working memory accuracy. A primary assumption made by Eysenck et al. (2007) in their Attentional Control Theory is that anxiety primarily affects the efficiency with which individuals perform cognitive tasks, and less so the effectiveness with which they perform. This is because it is possible for individuals to apply more effort to improve performance effectiveness, at the expense of efficiency. The present results suggest that anxiety can in fact also impact on performance effectiveness, particularly on visual working memory processes that are reliant on executive and perceptual attention. These results add to an emerging literature base that has demonstrated effects of anxiety on the neural correlates of visuospatial working memory (e.g., Moriya, 2018; Moriya & Sugiura, 2012; Qi, Ding et al., 2014; Qi, Chen et al., 2014), as well as on behavioural outcomes in visual and visuospatial working memory tasks (Jaiswal et al., 2018; Moreno et al., 2015; Spalding et al., 2021).

The results of Study 3 support those of Spalding et al. (2021; Study 2), who assessed shape and binding memory in a simultaneous, rather than sequential, binding task. In that study, as well as the present study, trait somatic anxiety was associated with a smaller proportion of correct responses specifically for binding memory, and not shape memory. Furthermore, in each study, there was no evidence for a deficit in binding effectiveness resulting from higher trait cognitive anxiety. This result provides further evidence that the somatic dimension of anxiety may be associated with performance deficits in a change detection task where the cognitive dimension is not. However, in the present study, trait cognitive anxiety was associated with a greater proportion of correct shape memory responses while trait somatic anxiety was not. This pattern was not observed by Spalding et al. (2021). Prior to further consideration of the results it is necessary to clarify that Spalding et al. focused exclusively on the analysis of trait anxiety as a continuous variable in their second study, while in the present study anxiety was analysed both as a categorical and continuous variable. Although the present results indicate support for the basic assumption within ACT (Eysenck et al., 2007) that higher levels of anxiety are associated with reduced cognitive performance, the reductions in performance observed here were generally found to be similar in both the moderate and high trait cognitive anxiety groups. That is, these deficits were not limited to only the individuals who reported levels of anxiety potentially indicative of an anxiety disorder, as measured by the STICSA (Ree et al., 2008). Instead, they suggest that individuals who report experiencing levels of anxiety beyond a relatively low level, may be susceptible to the cognitive effects detailed in the remainder of this chapter.

6.5.2 Trait cognitive anxiety and improved feature memory

A particularly intriguing finding with regard to trait cognitive anxiety was not only that moderate and high levels of anxiety were associated with significant cost of binding relative to shape memory, but – as per the MLM analysis - that shape memory accuracy significantly increased as trait cognitive anxiety increased. An explanation for this newly observed association may come from studies that have observed a positive relationship between trait social anxiety – which consists primarily of anxious cognitions (e.g., Hirsch & Mathews, 2012; Rapee, 1993; Wells, 1995) – and change detection performance (Moriya & Sugiura, 2012; Moriya, 2018). Although a positive association between anxiety and working memory performance is not a typical finding in the literature (see Moran et al., 2016), Moriya and Sugiura (2012) have suggested that socially anxious individuals may expend more effort to maintain a greater number of visual features in working memory (in order to better monitor other individuals' responses in social situations). While the same rationale regarding the monitoring of specifically social responses cannot be applied to the present results, it does provide a viable explanation as to why the shape memory improved as anxiety increased, but binding memory did not. If, as predicted by ACT (Eysenck et al., 2007), anxiety increases the influence of bottom-up attention at the expense of executive attention, it could be the case that highly anxious participants are better able to monitor and maintain visual information that does not require further elaborative processing or effortful maintenance (i.e., individual shapes rather than colour-shape conjunctions). However, when binding is required, the advantage afforded to memory for single features is abolished, due to impaired top-down attentional control, which is typically required for maintaining bindings that are presented sequentially (see Hitch et al., 2020).

It is therefore possible that the increased influence of perceptual attention is driven by anxious cognitions. Executive resources may be directed towards prioritising the monitoring of stimuli at the perceptual level. Simultaneously, higher-level working memory mechanisms directly linked to the central executive (e.g., the visuospatial sketchpad and episodic buffer, which are heavily influential in binding; Hitch et al., 2020) may then receive less executive support in the process. This rationale may also help to explain the shape memory advantage being limited to trait cognitive, and not trait somatic anxiety. If highly anxious individuals are expending more effort to monitor stimuli, this additional effort may be motivated by conscious anxious cognitions (a defining feature of social anxiety), rather than guided by involuntary, physiological, anxious responses. It should also be noted, though, that there was a significant positive linear relationship observed between trait cognitive anxiety and shape memory. This suggests that as trait cognitive anxiety increases, so too does visual working memory performance under these conditions. That is, benefits to working memory in these conditions are not only observed in those individuals who report levels of anxiety that, according to the STICSA, indicate the probable presence of an anxiety disorder. Visual working memory for individual features appears to improve more generally as trait cognitive anxiety increases.

6.5.3 Trait somatic anxiety and working memory capacity

Turning to the effect of trait somatic anxiety on performance effectiveness, this was observed within a three-way interaction. When asked to remember memory arrays consisting of three items, binding memory was worse than shape memory in those reporting moderate and high anxiety, but not low anxiety. This supported previous findings, and the predictions made, as to the effect of set size on performance. High trait anxiety has previously been associated with a working memory capacity of three items in a change detection task, as opposed to a capacity of four items which was associated with low trait anxiety (Qi, Chen, et al., 2014). This outcome has since been indirectly supported by behavioural data. High levels of worry have been associated with reduced response times for both feature and binding memory in memory arrays of three items (Moreno et al., 2015). High trait somatic anxiety has also been associated with reduced performance effectiveness for binding memory, but not shape memory, when participants were asked to remember three items (Spalding et al., 2021). The present findings would therefore suggest that negative effects of anxiety on performance effectiveness emerge under conditions in which individuals reporting moderate to high levels of anxiety are operating at or near the capacity limits of working memory (up to four items, e.g., Cowan, 2005), while less anxious individuals retain greater capacity to maintain a higher level of performance. In this case, the additional executive demand imposed by having to maintain fragile binding representations in the face of new representations – a key feature of the sequential binding task (e.g., Hu et al., 2014, 2016) – could be the factor responsible for reduced performance, suggesting a capacity-dependent deficit in working memory maintenance at high levels of trait somatic anxiety. It is therefore important for future work to confirm the extent to which effects of anxiety are capacity-dependent, accounting for individual differences in capacity.

The binding deficit observed at moderate-high levels of trait somatic anxiety is further contextualized by the analysis of trait somatic anxiety as a continuous variable. Multilevel modelling indicated that binding memory across set sizes decreased as trait somatic anxiety increased. Therefore, it would appear that while the moderate and high anxiety groups had greater difficulty maintaining binding performance relative to their own shape performance at a lower set size, increased anxiety was associated with a more general difficulty in binding, independent of memory capacity. Thus, there may be a particular aspect of the binding process that is more readily disrupted as trait somatic anxiety increases. Rather than a difficulty maintaining items within a limited capacity focus of attention, specifically via executive attention in the face of distraction, it is more plausible that there is a general deficit in keeping bindings intact within the focus of attention or visuospatial sketchpad. Hitch et al. (2020; see Figure 1.5) attribute the functions of an episodic buffer and focus of attention to the same component within working memory in their visual working memory model. Thus, if anxiety - cognitive or somatic - affects cognition by increased attention to verbal worries or physical sensations (i.e. non-visual, internal distractors), it would be reasonable to suggest that the buffer component, responsible for integrating information across sensory modalities, would be the affected component. Executive resources may not necessarily be limited, but the focus of attention may not be sufficiently directed towards task-relevant stimuli.

The impact of both cognitive and somatic anxiety on memory effectiveness may initially appear counterintuitive. Anxiety has typically been thought to impact on cognition through worry – a cognitive dimension of anxiety – which primarily occurs in the form of subvocal speech (Hirsch & Mathews, 2012; Rapee, 1993; Wells, 1995). Verbal-based worry is thought to engage the phonological loop (e.g., Markham & Darke, 1991) and subsequently demand executive resources (Eysenck et al., 2007). As such, one might expect that the cognitive dimension of anxiety specifically would be associated with reduced binding performance. Indeed, where trait cognitive and somatic dimensions have been assessed separately, the cognitive dimension - but not the somatic - has consistently been associated with reduced attentional control and cognitive processing abilities (Edwards et al., 2015; 2016; 2017; Mella et al., 2020; although see Schoen & Holtzer, 2017). However, the negative impact of somatic anxiety on binding effectiveness has indeed been observed previously (Spalding et al., 2021). Also, previous research has demonstrated that physiological responses to an ongoing stressor negatively influence performance in visuospatial working memory tasks (e.g., Shackman et al., 2006; Vytal et al., 2013). Further discussion of the factors underlying the potential impact of trait somatic anxiety on working memory is provided in light of the results obtained in Study 4 of this thesis (see Sections 7.5.1, 7.5.2, and 8.5.1).

6.5.4 Trait anxiety and memory efficiency

Reduced binding efficiency, as compared to shape efficiency, was observed at moderate and high levels of trait cognitive anxiety, but not at low levels of trait cognitive anxiety. This pattern was also observed for trait somatic anxiety, but specifically when three memory items were presented, and not four items. These results supplement the effectiveness data by demonstrating that performance efficiency decreases as anxiety levels increase, which is a key assumption of Attentional Control Theory (Eysenck et al., 2007). The outcomes for trait cognitive anxiety suggest that cognitive experiences of anxiety may negatively impact on efficient binding independent of memory load, potentially suggesting that cognitive efficiency deficits associated with anxiety are related to specific working memory mechanisms required for binding, such as the episodic buffer, more so than working memory capacity. In Hitch et al.'s (2020) most recently proposed model of visual working memory (see Section 1.4.2), the episodic buffer is likened to the focus of attention in which intact object files are stored. If attentional focus is reduced as anxiety increases and maintaining bound object representations requires greater attentional focus than maintaining individual features, this would explain the reduction in binding memory efficiency compared to shape memory as anxiety increases. Trait somatic anxiety, by comparison, may in fact be associated with capacity limitations, as indicated by the reduction in binding efficiency compared to shape efficiency specifically at set size 3, but not at set size 4. This is further supported by the finding that the difference in shape and binding efficiency was greater in the high anxiety group than in the moderate group. This finding suggests that trait somatic anxiety becomes even more impactful on processing efficiency at levels of anxiety that indicate the probable presence of an anxiety disorder, and that this occurs at lower memory loads. This finding provides further support, in the form of behavioural data, for the CDA amplitude data provided by Qi, Chen, et al. (2014), whereby observed amplitudes reached asymptote under three items at higher levels of anxiety and four items at lower levels.

The present results differ from Spalding et al. (2021; Study 2) in that, in the present study, a significant effect of anxiety was found when performance efficiency was operationalized as the ratio of performance accuracy to response times in correct trials (e.g., Edwards et al., 2016), rather than simply correct response times. By comparison, Spalding et al. found a negative association between both cognitive and somatic anxiety and response times in trials in which participants responded correctly in the change detection task. This applied across both binding and shape memory. They did not however find significant effects on efficiency operationalized in the manner it was presently. One possible explanation for this discrepancy in the results is the difference in stimulus presentation format between studies. Spalding et al. presented objects to participants simultaneously, rather than sequentially as in the present study. Given that sequential presentation is considered more demanding than simultaneous (see Hitch et al., 2020), it could be that efficiency was more dependent on performance effectiveness in the present study than in Spalding et al.'s task. Therefore effects of anxiety on correct RTs only appeared here when also accounting for performance accuracy rates.

6.5.5 Effects of anxiety and memory type on serial working memory

Looking at performance for arrays of three objects, the results support greater cost-free processing of shape memory as compared to binding memory. Participants were significantly better at remembering the final item in the memory sequence than the first item when asked to recognise a shape cue, but this effect was not replicated for binding memory. In fact, the middle serial position became significantly harder to remember than the first item when participants were asked to recognise bindings. This suggests a greater fragility of the mid-sequence item that materialises specifically under binding conditions. Regarding data at set size four, performance was significantly greater at serial position four than at the other serial positions, regardless of whether an individual shape or binding was to be remembered. These results reflect a recency effect observed in previous binding research which suggests that the final item within a memory sequence is remembered in a relatively cost-free manner (Allen et al., 2006; Brown et al., 2017; Hu et al., 2014; Hu et al., 2016).

Common across performance at each set size was the significantly worse performance at serial position two that emerged specifically within the binding condition. Previous research has suggested that such a serial position curve is particularly pronounced in older adults, regardless of whether they are asked to remember individual features or feature combinations (Brown et al., 2017). The present results suggest that this earlier finding extends to a binding-specific deficit for this serial position in younger adults. It is possibly the case that it is difficult for adults across the lifespan to recall this item due to interference from both the preceding item in the memory sequence and subsequent items. Certainly, proactive interference from the first item in the sequence was particularly apparent at set size three, wherein the significant reduction in performance for the mid-sequence item was relative to the first item, but not the last item, in the sequence. Allen et al. (2021) have also shown a reduction in memory for mid-sequence items but found that performance for this item can be boosted with strategic prioritisation of attention towards the item. Their results provide further support for the view that executive attention can be drawn upon to mitigate perceptual interference (see Hitch et al., 2020).

Finally with regard to serial position, the lack of a significant interaction between anxiety and serial position suggests that there is not clear evidence for a stronger role of top-down or bottom-up attention influencing working memory performance in anxiety in the context of the present paradigm. This finding is also consistent with Spalding et al. (2021, Study 1). Although the positive association between trait cognitive anxiety and shape memory would suggest higher trait cognitive anxiety reflects better processing of stimuli that require less elaborative processing, that is, individual features, this was not reflected in a pronounced recency effect within this group. This would have indicated that as trait cognitive anxiety increases, stimuli are more easily processed relatively automatically, but this was not the case. Similarly, regarding binding memory, moderate and high trait cognitive and somatic anxiety groups showed a greater impairment for binding compared to shape memory than did the low groups. Based on this, it would have been reasonable to expect that they may have experienced greater difficulty remembering bindings at earlier serial positions, given that bindings are particularly vulnerable to being overwritten by subsequent stimuli. However, this was not the case. Discussion of the serial position data obtained in Study 4 (see Section 7.5.5) provides further context for the role of trait somatic anxiety in maintaining memory representations in a sequential binding task, but the data from the present study suggest that anxiety may impact on cognitive performance through a working memory mechanism other than executive or perceptual attention, as discussed in Sections 6.5.2 and 6.5.3.

6.5.6 Limitations and future directions

Study 3 was designed, in part, to explain why there were no significant effects of anxiety on visual feature binding performance in Studies 1 and 2, considering the wider available literature. To do this, performance was compared for memory arrays of three and four items. Reduced memory performance has been associated with anxiety in previous studies using three memory items (Moreno et al., 2015; Spalding et al., 2021). However no associations were observed in Studies 1 and 2 of this thesis, which used four memory items. In addition, participants' response method was changed from cued recall via oral response to single-probe recognition via keypress, as it is via probe recognition and change detection responses that effects of anxiety on behavioural measures of visual and visuospatial working memory have typically been observed previously (e.g. Jaiswal et al., 2018; Moreno et al., 2015; Spalding et al., 2021). While the results suggest that an aspect of the methodology would explain the lack of effects of anxiety observed in Studies 1 and 2, it is difficult to specify whether this was due to the change in response method or presentation conditions. A future study should assess cued recall for shape and binding memory across set sizes of three and four items in order to determine the specific cause of these different results. Indeed, performance between these response methods could be compared directly.

It should be noted that the present results to some extent contradict those reported by Spalding et al. (2021, Study 1), in which there was no significant performance deficit associated with high trait cognitive or somatic anxiety across effectiveness and efficiency outcomes in a sequential binding task. This was despite stimuli being sequentially presented for a similar duration as the present study in one task condition. One potential explanation for this difference in results is that in the present study there was an inter-stimulus interval of 250 ms during the presentation phase that was not present in Spalding et al.'s sequential task. There is evidence that increased stimulus presentation time improves visual working memory precision, but reduces capacity, at test during negative emotional states (Long et al., 2020; Spachtholz et al., 2014). Long et al. (2020) interpreted their findings in the context of Ye et al.'s (2017) two-step model of selective attention. According to the assumptions of this model, individuals might only focus on maintaining as many memory representations as possible at an early task phase, consolidating these into accurate representations as the time available to encode items is increased. This may explain why binding effectiveness was negatively impacted at higher levels of trait somatic anxiety, assuming that the feature binding task employed did not rely on precision of responses but was instead a purer measure of representation capacity, and that negative emotional traits also impact on capacity as well as states. However, a limitation of this interpretation is that, in the present study, there was no interaction between anxiety and serial position across conditions. This suggests that participants did not focus on consolidating early-sequence items as compared with subsequent items as the two-step model of selective attention would suggest. Therefore, while the findings of Long et al. (2020) and Spachtholz et al. (2014) implicate a role of presentation time in influencing performance in those with higher anxiety, Long et al.'s explanation does not fit with the present data. Further research is therefore required in order to determine the impact of anxiety on working memory capacity in comparison with working memory precision, particularly in the context of binding. This could be addressed using methods that allow for responses regarding memory items to be made on a continuous scale in the context of anxiety in binding tasks, for example, making colour judgement responses via gradient displays (e.g. Bays et al., 2009). To more accurately determine whether the effect of anxiety is specific to the conditions used in the present study as compared to Spalding et al. (2021), direct comparisons of conditions including inter-stimulus intervals with conditions excluding inter-stimulus intervals should also be considered. This would firstly address the identified discrepancy in results and help to clarify the extent to which encoding and consolidation time may influence cognitive performance in anxiety.

It is also necessary to further consider why trait somatic anxiety was negatively associated with binding memory effectiveness, while trait cognitive anxiety was associated with improved shape memory effectiveness. There is recent evidence that somatic, but not cognitive, anxiety may impair neuropsychological function in older adults (Schoen & Holtzer, 2017). However, it has also been suggested that trait cognitive, but not somatic, anxiety negatively impacts executive functions (Edwards et al., 2015; 2016; 2017). Based on the limited evidence available, it is only possible to make tentative suggestions as to why the distinction between anxiety domains was observed in the present study. Studies of chronic pain show that somatic pain demands attention (Eccleston & Crombez, 1999) and that performance in an attentionally-demanding task is reduced when participants report higher levels of pain and somatic self-awareness. Thus it is possible that the somatic subscales of the STICSA reflect the attention paid by an individual to their somatic experiences, regardless of whether they accurately reflect these experiences. Indeed, the somatic scale has been shown to differ from the cognitive scale in correlating less strongly with measures of depression, which may suggest that the somatic subscale reflects a unique anxiety factor, for example, physiological distress (Roberts et al., 2016). In turn, then, the somatic subscale may be more reliable in indicating levels of anxiety as opposed to the cognitive subscale which is more highly correlated with measures of depression. Ultimately, there remains a need to further explore the relative impacts of each dimension of trait anxiety on visual working memory to better understand the mechanisms by which they impact on cognition.

6.6 Chapter summary

This chapter reported the findings of Study 3, which examined the impact of trait anxiety on shape and binding memory in a sequential binding task, in which memory load was varied (sets of three or four items). It would appear that trait cognitive anxiety may be associated with improved visual working memory when to-be-remembered stimuli require fewer executive resources or less elaborative processing to be maintained in working memory. These results may reflect the enhanced perceptual processing associated with high anxiety assumed by Eysenck et al. (2007) in their Attentional Control Theory. It is possible that individuals reporting high trait cognitive anxiety are better at maintaining a greater number of individual features in memory due to increased perceptual receptivity and monitoring of the environment, without need to employ additional executive resources to attend to specific stimuli. By comparison, trait somatic anxiety may negatively impact visual working memory when additional maintenance or elaborative processing is required, suggesting that when individuals are more prone to experiencing somatic anxiety, the additional executive demand of remembering bindings over shapes cannot be met due to the reduced executive control available. This reflects the imbalance described within ACT whereby higher perceptual demand is less easily managed due to reduced top-down control of attention. Regarding the effect of high trait somatic anxiety as measured by the STICSA, this may reflect greater cognitive interference – or interference more specific to the maintenance of bound representations – in memory than the cognitive subscale itself. This would explain why individuals reporting high trait somatic anxiety were less effective in maintaining bindings over a memory sequence.

7 Study 4 - Impacts of anxiety on visual working memory as a function of set size and cognitive load

7.1 Chapter overview

As with Study 3, the present Study 4 was designed to follow-up on the non-significant effects of anxiety observed in Studies 1 and 2, reported in Chapters 4 and 5. In Study 4, the possibility that anxiety may interact with cognitive load to affect working memory performance was assessed. Participants' memory for sequences of three or four coloured shapes was tested across varying levels of cognitive load as determined by a dual task manipulation. In a control condition, participants performed a concurrent number repetition task as in Studies 1-3, to limit verbal processing. In a cognitive load manipulation, however, participants performed a concurrent, attentionally-demanding task, in which they were asked to count backwards from the presented number in sets of three rather than simply repeating it. The sequential binding task involved change detection performance as in Study 3, and once again participants were grouped according to anxiety scores; either low, moderate, or high. Contrary to the initial hypotheses informed by Attentional Control Theory, no effect of trait cognitive anxiety on binding performance accuracy was observed. This result was however in line with Studies 1-3. A main effect of trait somatic anxiety was observed, in which the low anxiety group showed better binding memory accuracy than the moderate and high groups across set size and cognitive load conditions. No other effects relating to anxiety were observed. This outcome was broadly in line with the effects of trait somatic anxiety observed in Study 3, and in previous published research, where higher levels of trait somatic anxiety have been found to be associated with a reduction in visual feature binding memory. Therefore, the results point to an emerging pattern whereby specifically trait somatic anxiety is associated with visual working memory binding deficits. The differences between conditions in which this association has been observed are considered in the discussion section for this particular study (Section 7.5), with the aim of providing an explanation for the different relationships between the anxiety dimensions and visual working memory.

7.2 Study 4 – Introduction

According to Attentional Control Theory (ACT; Eysenck et al., 2007), high anxiety is more likely to disrupt cognitive performance in a task that also involves a high concurrent cognitive load. Indeed, there is evidence that an additional executive load disrupts attentional control when participants are more anxious. Berggren et al. (2012) found that, in a visual search task, participants reporting high trait anxiety showed slower response times as well as longer latencies for saccades towards target stimuli in a cognitive load condition (counting backwards in threes). In contrast, non-anxious participants did not show such a decrement in performance. Berggren et al. (2013) found that, under load, inhibitory control was reduced in an anti-saccade task (i.e., latencies of saccades away from to-be-ignored stimuli increased). In this case, inhibitory control was reduced when participants had to simultaneously recognise the specific pitch of auditory tones, rather than the tones themselves, with the effect exacerbated in those reporting high levels of trait anxiety. Reduced inhibitory control under load may also interact with the emotional valence of task stimuli. Judah et al. (2013) found that socially anxious participants made faster responses in a dot-probe task assessing the attentional selection of faces when the faces were disgusted rather than neutral, and also when completing a concurrent 2-back task as compared to a control condition. By comparison, non-socially anxious participants' attentional biases to faces did not vary with additional executive load. Thus, there is some evidence supporting the assumption within ACT that anxious participants are more likely to have their cognitive performance disrupted by the additional demands of further cognitive load.

There is, however, conflicting evidence as to the interactive effects of anxiety and cognitive load on similar measures of attentional control as those described above. Basanovic et al. (2018) found that participants reporting high levels of trait anxiety showed impaired visual search inhibitory control, as measured by saccade latencies, independent of an additional cognitive load. Interestingly, increased cognitive load improved inhibitory control across participants reporting either low or high levels of trait anxiety. This followed earlier evidence from Najmi et al. (2014) that a high state anxiety group and diagnosed generalized anxiety disorder group showed less interference from distractors in the test phase of the Attention Network Test under high load (counting backwards from 100 in threes) than under low load (counting backwards from 100 in ones). By comparison, control groups showed no performance difference between load conditions. These latter findings are at odds with the assumptions included in Attentional Control Theory (Eysenck et al., 2007) that high anxiety is more likely to disrupt attentional control under high cognitive load, due to increased occupation of working memory resources. One explanation is that under high load, highly anxious participants' cognitive resources are redirected back towards the task demands, in turn reducing their anxiety level (King & Schaefer, 2010; Vytal et al., 2012). However, this finding is limited to anxious state responses, i.e. startle reflexes and subjective anxiety scores, and therefore the role of trait anxiety in this process should be further explored.

Outside of the anxiety literature, the negative effect of increased cognitive load on visual working memory has been well established across feature binding studies using dual-task methodologies. Allen et al. (2006) asked participants to perform a concurrent executively demanding task (counting backwards in sets of one or three) during the encoding and maintenance phase of a simultaneous binding task. They found that individual feature memory and binding memory were similarly reduced as compared to a control condition. This suggested that the binding of visual features does not rely on executive resources to a greater degree than the recognition of individual features. This pattern of results was replicated by Allen et al. (2012) across longer stimulus presentation conditions and continuation of the concurrent task through the test phase. An important finding from Allen et al. (2012) in the context of the present study was that binding memory and individual feature memory were similarly impaired by a concurrent backwards counting task regardless of whether participants were asked to remember sets of three or four items.

As discussed in Section 1.4.1, however, bindings do appear to be particularly fragile to overwriting from subsequently presented stimuli when these stimuli are presented sequentially. This suggests that binding may in fact require attention to a greater extent than individual feature memory. When features and bindings are presented sequentially in three-item sequences, memory for the earlier items is reduced by an additional cognitive load from a dual task (Allen et al., 2009, 2014, 2017; Karlsen, 2010). Attentional refreshing, dependent on executive resources, is seemingly required to maintain items in memory in the face of new information (see Hitch et al., 2020). Binding does appear to be subject to negative effects of an additional cognitive load when memory items are presented sequentially, and when participants are asked to respond via cued recall. Specifically, positive effects of prioritising items in memory are reduced when a concurrent backwards counting task is also involved (Hu et al., 2016). This would implicate an increased role of the central executive in maintaining bindings, particularly when presented sequentially.

Several studies have been conducted in recent years that assess the impact of anxiety on visual working memory performance subject to primarily perceptual factors (memory type in Moreno et al., 2015; memory type and presentation method in Spalding et al., 2020; suffix interference in the present Study 2; memory load and memory type in the present Study 3). However, research assessing whether anxiety may interact with manipulations of executive control to affect visual working memory has been less extensive (although Study 1 of this thesis encouraged participants to prioritise specific items in working memory). Given that ACT (Eysenck et al., 2007) assumes reduced executive attention with higher anxiety, and it has been demonstrated that increased executive load affects visual feature binding, it would be of interest to determine whether anxiety affects binding by interacting with a load manipulation. While Study 1 (see Chapter 4) was designed to assess whether participants could use top-down executive control to better remember specific items in a memory sequence, and whether this was dependent on anxiety levels, the present study reported in this chapter was designed specifically to assess whether an additional load may impact on sequential binding depending on anxiety levels.

The present study was based on evidence that an additional cognitive load may impair executive attentional control to a greater extent in those with higher trait anxiety (Berggren, 2012; Berggren 2013; Judah et al., 2013), but also evidence from Studies 1 and 2 (Chapters 4 & 5). In these latter studies, there were no significant differences observed between anxiety groups in memory for early-sequence items in a sequential binding task. Thus, it appeared that trait anxiety did not serve as an additional executive load during the task. It was therefore of interest to determine whether anxiety may impact sequential binding performance by interacting with cognitive load.

7.2.1 Hypotheses

In the present study, participants classified as reporting either low, moderate, or high levels of trait anxiety completed a change detection sequential binding task. Performance was compared under a control condition (concurrent articulatory suppression) and a cognitive load condition (a concurrent backwards counting task). As in Study 3, reported in Chapter 6, performance was also compared across memory set sizes (either three or four items). As explained in Section 6.2, this was because there is previous evidence of a negative effect of anxiety on visual working memory, specifically for sets of three memoranda (Moreno et al., 2015; Spalding et al., 2020; see also Qi, Chen et al., 2014). The results of Study 3 also suggest a role of set size in performance, with a deficit in binding memory - as compared to shape memory – at moderate and high levels of trait somatic anxiety specifically for arrays of three items.

For Study 4, a three-way interaction was predicted. If higher trait anxiety reduces executive attentional control, a binding memory deficit may be observed in the high trait anxiety group compared to lower anxiety levels, particularly during a higher cognitive load condition. Furthermore, this effect was expected to be revealed when participants were asked to remember three, rather than four, memory items.

7.3 Study 4 – Method

This study was preregistered with the Open Science Framework prior to data collection. The pre-registration for the study can be found at https://osf.io/8bqje, with underlying data to be made available after publication.

7.3.1 Participants

Participants were 68 young adults (12 male, 56 female) aged 17-33 years (*M* = 21.38, *SD* = 3.81). Their mean years of education was 14.90 (*SD* = 2.15). All participants reported normal/corrected-to-normal vision, and no memory impairments. Note, the original target sample size was 96. However, due to sudden COVID-19-related lab closures, the study had to be terminated earlier than planned. A power analysis conducted using MorePower 6.0 (Campbell & Thompson, 2012) indicated that the initial target sample size would have been sufficient to detect a moderate-to-large effect (n^2_p = .10), for the three-way interaction or main effect of anxiety, α = .05, power = .80. A retrospective power analysis indicated that the final sample size of 68 was sufficient to detect a large-sized effect (n^2_p = .13) for a three-way interaction or main effect of anxiety, α = .05, power = .80.

7.3.2 Design

A 3 (anxiety group; low, medium, high) x 2 (set size; three, four) x 2 (cognitive load; control, backwards counting) mixed design was used. Anxiety groups were determined according to the criteria detailed in Section 3.4.2. The high group consisted of participants reporting anxiety levels above a suggested threshold for probable presence of an anxiety disorder (> 23 for the cognitive subscale and > 18 for the somatic subscale; van Dam et al., 2013). The low and moderate groups were determined based on a split of the remaining participants' scores as close to the median as possible (see Table 7.1). The dependent variables were memory accuracy and memory efficiency (see Section 3.4.2).

Table 7.1 Participant demographic information by anxiety group for Study 4.

	N	Anxiety Min–Max, *M* (*SD*)	Age *M* (*SD*)	Sex (M:F)	Yrs Education *M* (*SD*)
Trait Cognitive Anxiety	68				
Low	26	11-17, 14.77 (2.14)	22.23 (4.36)	6:20	14.88 (2.96)
Moderate	25	18-23, 20.96 (1.58)	20.52 (3.07)	3:22	14.76 (1.56)
High	17	25-34, 28.82 (3.43)	21.35 (3.80)	3:14	15.11 (1.36)
Trait Somatic Anxiety	68				
Low	19	11-14, 12.68 (1.25)	22.37 (4.99)	3:16	14.73 (3.46)
Moderate	19	15-18, 16.58 (1.12)	20.89 (3.05)	4:15	14.79 (1.23)
High	30	19-34, 24.20 (4.66)	21.07 (3.36)	5:25	15.07 (1.48)

7.3.3 Procedure

Task materials were as detailed in Section 3.4.3. As in all previous studies reported in this thesis, participants first completed the Trait then State versions of the STICSA, followed by the DASS. They then completed the change detection task. The experimental procedure was as reported in Section 3.5.2, and the trial procedure was the same as in Section 6.3.3, with the exception that only binding memory was focused upon in this study. A trial procedure is presented in Figure 7.1.

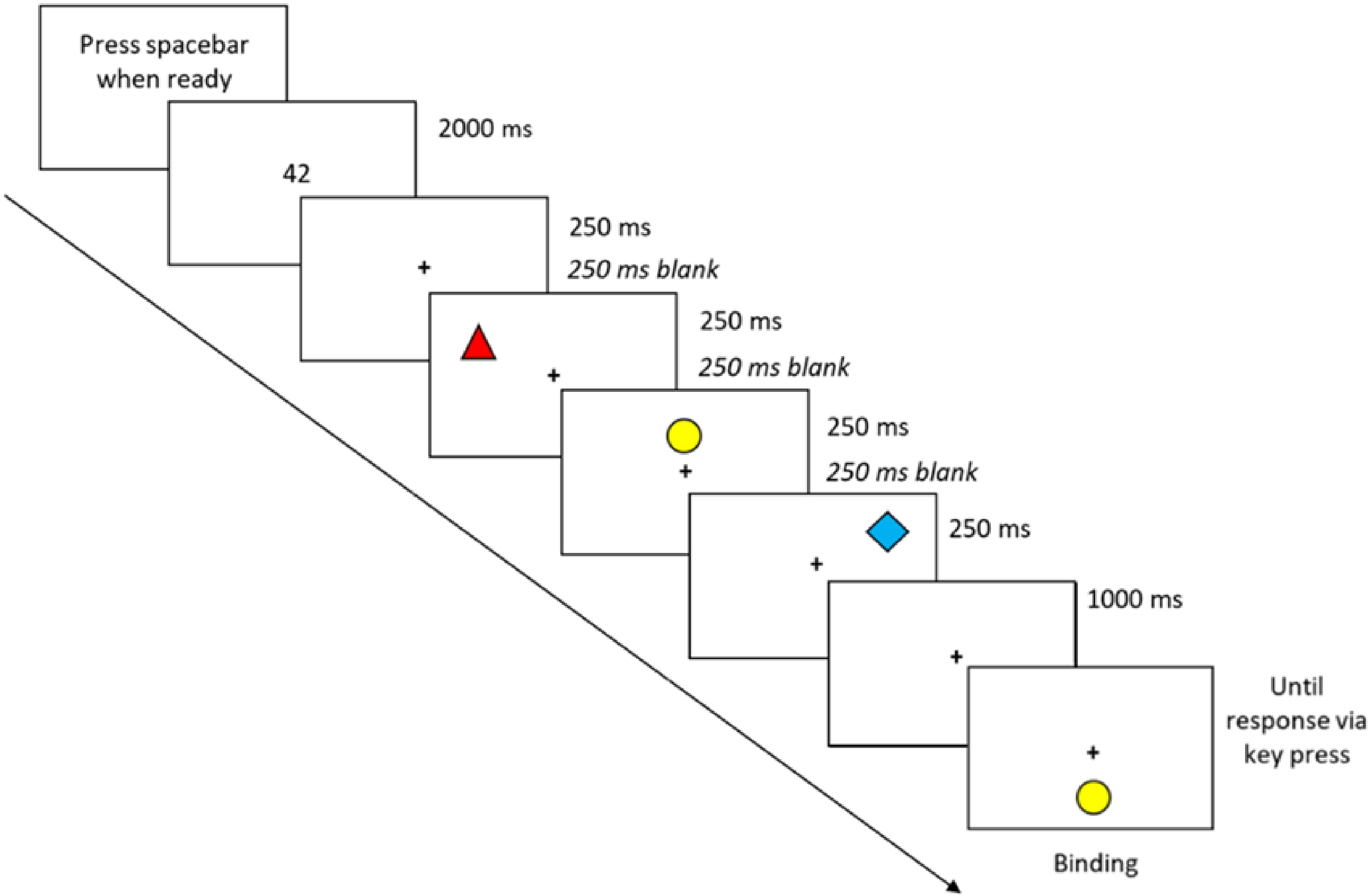

Figure 7.1 An example trial procedure in which the test item was present in the array. This depicts one trial. Participants were instructed prior to each trial block whether to repeat or count back from the 2-digit number. Stimuli are not drawn to scale.

Stimulus presentation times and locations on screen were the same as in Study 3 (see Section 6.4.5). Participants pressed the spacebar to begin each experimental trial. A fixation cross was shown in the centre of the screen for 500 ms followed by a 500 ms black screen. A two-digit number was then shown for 2000 ms. In the control condition, the participant immediately began to repeat the two-digit number out loud at a rate of 1-2 repetitions per second. In the cognitive load condition, however, the participant immediately began to count backwards from the number in sets of three. In both cases, they were asked to continue the articulation task until they had made their response at the end of the trial. The approximate articulation rate was demonstrated to participants by the experimenter prior to the task. Repetitions and counts were recorded manually by the experimenter. Correct counts per trial were calculated as the total number of times the participant correctly spoke aloud the number in the backwards sequence (i.e. correctly subtracted three from the preceding number). Following a 250 ms blank screen, each study item was presented for 250 ms, separated by blank screens for 250 ms. Each item was presented in a row just above the centre of the screen, from left to right. A 1000 ms blank screen followed the final sequence item before the test probe was presented at the centre of the bottom half of the screen. Participants indicated whether they thought the test probe had been presented in the initial array via a keypress, pressing the 'z' key if they thought the item was the same as one presented in the memory array, and the 'm' key if they thought the item was different from those presented in the memory array. Participants were debriefed following the experimental phase. Instructions provided to participants at the beginning of each block can be viewed in Appendix L.

7.3.4 Data analyses

Analyses followed the general approach detailed in Section 3.4.2. As change detection responses require a same-different response choice, chance performance level for performance effectiveness data was 50%. Although trait cognitive anxiety was the main variable of interest, as per the preregistration, it was also important to determine whether anxiety dimension influences the findings. Therefore, results are provided for the main analyses focusing on trait cognitive anxiety as well as exploratory analyses focused on trait somatic anxiety. Bonferroni corrections were applied automatically in SPSS 27 for pairwise comparisons. Where paired samples t-tests were conducted, the applied correction is noted for the specific analysis. Bayes factors and exploratory analyses are also reported to complement the results of the main analyses. These include multilevel modelling which treat trait cognitive and somatic anxiety as continuous variables, and analyses of hit (correct detection of change at test) and false alarm (incorrect reporting of a change at test) data. As noted in Chapter 3, Section 3.3.4, the measures of performance efficiency reported in Section 6.4.4 vary from those detailed in the initial preregistration. As opposed to operationalizing efficiency as both overall response times and correct response times, it was considered more theoretically relevant to consider correct response times (e.g., Spalding et al., 2021) as well as using the following equation (e.g., Edwards et al., 2015; Edwards et al., 2016):

$$Efficiency = \frac{proportion\ correct\ responses}{correct\ RT}\ x\ 1000$$

7.4 Study 4 – Results

7.4.1 Articulatory suppression and backwards counting

The mean number of repetitions in the control condition and correct counts in the cognitive load condition can be viewed in Table 7.2. Although these indicate fairly consistent performance across conditions, 3 (trait anxiety group; low, moderate, high) x 2 (set size; three, four) mixed ANOVAs were conducted in order to assess whether anxiety levels were associated with significant variation in repetitions and/or correct counts. There was a two-way interaction between trait cognitive anxiety and set size in the control condition, $F(2, 65) = 5.68$, $MSE = .375$, $p = .005$, $n^2_p = .15$. Bonferroni-corrected paired t-tests (to meet significance, p-value $< .016$) conducted within each anxiety group indicated that the high trait cognitive anxiety group made fewer repetitions at set size three than at set size four, $t(16) = -3.79$, $p = .002$, but there was no variation between conditions in the low and moderate groups (all $p > .06$). There were no significant effects on backwards counting (all $p > .12$).[13]

[13] The patterns of mean repetitions and correct backwards counts were the same when analysing data using trait somatic, rather than trait cognitive, anxiety.

Table 7.2 Mean number of articulations (AS rates; with *SD*s) and correct counts in the concurrent task conditions across anxiety groups, set size and memory type.

	AS rates		Correct counts	
	Set Size 3	**Set Size 4**	**Set Size 3**	**Set Size 4**
Trait cognitive anxiety				
Low	4.45 (0.87)	4.20 (0.90)	1.94 (0.44)	1.90 (0.52)
Moderate	4.12 (0.91)	4.48 (1.39)	1.76 (0.47)	1.84 (0.59)
High	3.96 (1.16)	4.55 (1.09)	1.66 (0.56)	1.82 (0.54)
Trait somatic anxiety				
Low	4.35 (0.83)	4.22 (0.78)	1.77 (0.48)	1.89 (0.50)
Moderate	4.43 (1.01)	4.39 (1.11)	1.85 (0.37)	1.79 (0.52)
High	3.98 (1.00)	4.50 (1.35)	1.79 (0.57)	1.89 (0.60)

7.4.2 Performance effectiveness

Performance effectiveness data were analysed using 3 (trait anxiety; low, moderate, high) x 2 (set size; three, four) x 2 (cognitive load; control, backwards counting) mixed factorial ANOVAs. Mean performance effectiveness data for trait cognitive and somatic anxiety can be viewed in Table 7.3 (see Appendix M for correlations amongst key variables).

Trait cognitive anxiety. Regarding trait cognitive anxiety, there were significant main effects of set size, $F(1, 65) = 22.41$, $MSE = .007$, $p < .001$, $n^2_p = .26$, $BF > 10,000$, and cognitive load, $F(1, 65) = 58.07$, $MSE = .007$, $p < .001$, $n^2_p = .47$, $BF > 10,000$. The interaction between these variables was not significant, nor were there any significant effects relating to trait cognitive anxiety (all $p > .24$, all $BF < 0.29$), an outcome supported by the exploratory multilevel modelling (all $p > .12$; see 392 for full fixed-effects outcomes).[14]

Table 7.3 Mean performance effectiveness data (with *SD*s) for each trait cognitive and somatic anxiety group within each trial block.

	Control		**Cognitive load**	
	Set Size 3	**Set Size 4**	**Set Size 3**	**Set Size 4**
Trait cognitive anxiety				
Low	.67 (.08)	.61 (.09)	.57 (.11)	.54 (.07)
Moderate	.67 (.12)	.61 (.09)	.58 (.10)	.54 (.08)
High	.63 (.12)	.60 (.09)	.58 (.10)	.51 (.06)
Trait somatic anxiety				
Low	.69 (.07)	.64 (.09)	.63 (.09)	.57 (.09)
Moderate	.67 (.09)	.59 (.10)	.54 (.10)	.52 (.06)
High	.65 (.13)	.60 (.07)	.57 (.09)	.52 (.07)

Regarding the main effects, Bonferroni-corrected pairwise comparisons showed that, as expected, accuracy was significantly more accurate at set size three ($M = .62$, $SD = .09$) than at set size four ($M = .57$, $SD = .06$), $t(67) = 4.87$, $p < .001$, $BF >$

[14] Analyses were also conducted using state cognitive and somatic anxiety scores to form the anxiety groups. In each case there were no significant effects regarding either anxiety scale (all $p > .12$).

10,000, and more accurate in the control condition (*M* = .63, *SD* = .08) than in the backwards counting condition (*M* = .55, *SD* = .07), $p < .001$, *BF* > 10,000. [15]

Exploratory 3 (trait cognitive anxiety) x 2 (set size) x 2 (cognitive load) ANOVAs conducted on hit and false alarm rates indicated that it was specifically false alarms that drove the main effects of set size, $F(1, 65) = 27.76$, $MSE = .015$, $p < .001$, $n^2_p = .30$, *BF* > 10,000, and cognitive load, $F(1, 65) = 63.08$, $MSE = .019$, $p < .001$, $n^2_p = .49$, *BF* > 10,000, with no other significant effects observed (all other $p > .25$, all other BF < 1.10). There were no main effects or interactions regarding hit data (all $p > .21$, all *BF* < .44). Mean hit and false alarm data can be viewed in Table 7.4.

[15] Including self-reported depression as a covariate did not affect the pattern of significant findings (all non-significant $p > .28$). However including stress as a covariate removed the significant effect of set size ($p = .12$). The pattern of significant findings was also the same when excluding participants who reported currently taking medication for anxiety and/or depression, or those who did not indicate their medication status ($N_{EXCLUDED} = 5$; all non-significant $p > .17$).

Table 7.4 Mean hit and false alarm data (with *SD*s) in each trait cognitive anxiety group across set size and cognitive load conditions.

	Control		**Cognitive load**	
	Set Size 3	**Set Size 4**	**Set Size 3**	**Set Size 4**
Hits				
Low trait cognitive anxiety	.70 (.19)	.65 (.20)	.67 (.15)	.62 (.18)
Moderate trait cognitive anxiety	.66 (.19)	.64 (.15)	.62 (.15)	.62 (.15)
High trait cognitive anxiety	.61 (.18)	.61 (.17)	.62 (.13)	.59 (.23)
False alarms				
Low trait cognitive anxiety	.34 (.16)	.51 (.21)	.45 (.18)	.55 (.17)
Moderate trait cognitive anxiety	.31 (.15)	.49 (.18)	.40 (.13)	.53 (.19)
High trait cognitive anxiety	.34 (.14)	.44 (.22)	.43 (.18)	.56 (.24)

Trait somatic anxiety. Regarding trait somatic anxiety, alongside the main effects of set size and memory type described above, there was additionally a main effect of trait somatic anxiety, although this only received weak support from the Bayesian analysis $F(2, 65) = 4.71$, $MSE = .014$, $p = .012$, $n^2_p = .13$, $BF = 2.93$ (see Figure 7.2). There were no interactions observed (all $p > .14$, all $BF < 0.31$).

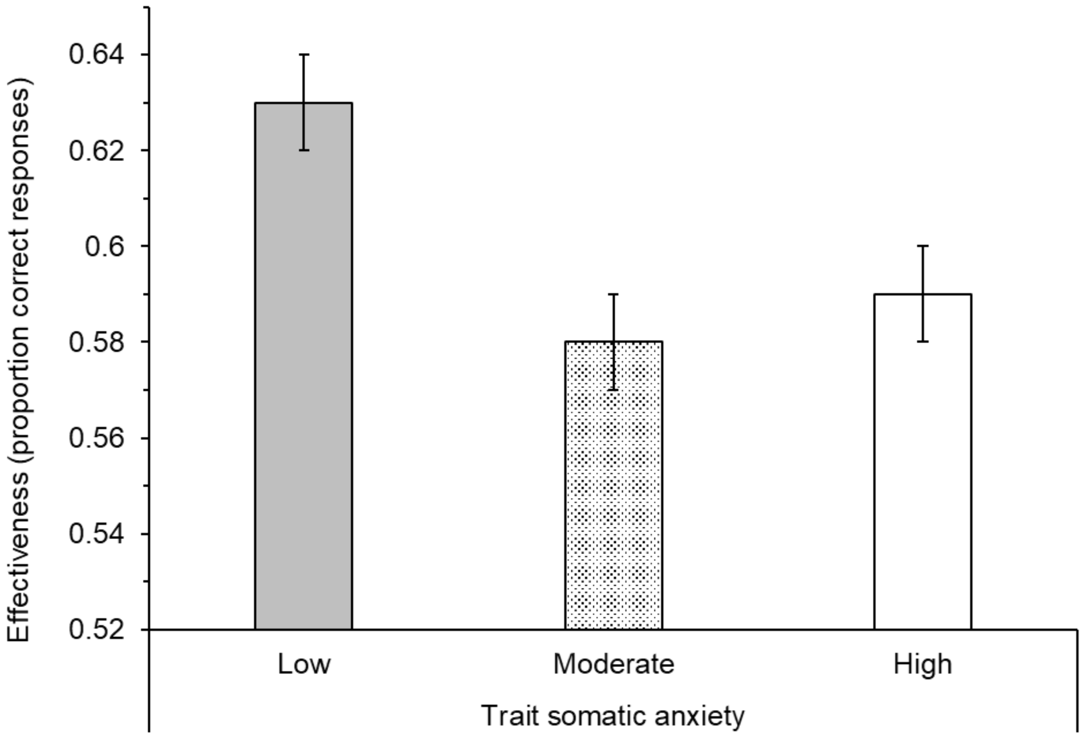

Figure 7.2 Performance effectiveness (with *SD*s) as a function of trait somatic anxiety group.

Following up the main effect of trait somatic anxiety, Bonferroni-corrected post-hoc pairwise comparisons indicated that the low trait somatic anxiety group ($M =$

.63, *SD* = .06) was significantly more accurate than the moderate trait somatic anxiety group (*M* = .58, *SD* = .06), *p* = .033, *BF* = 7.24. Also, the low trait somatic anxiety group was significantly more accurate than the high trait somatic anxiety group (*M* = .59, *SD* = .06), *p* = .021, *BF* = 10.23. However, there was no significant difference between the moderate and high groups, *p* = 1.00, *BF* = 0.09. The multilevel analysis showed no significant interactions, nor was the main effect of trait somatic anxiety significant (all *p* > .28). This supports the results of the frequentist analyses suggesting that the main effect of anxiety was nonlinear, as can be seen in Figure 7.2.[16]

Exploratory 3 x 2 x 2 ANOVAs initially indicated that the main effect of trait somatic anxiety related specifically to hit rates, $F(2, 65) = 4.05$, $MSE = .060$, $p = .022$, $n^2_p = .11$, *BF* = 2.64, and not false alarms (*p* = .052, *BF* = 1.26). However, the effect on hit rates was unreliable, as Bonferroni-corrected post hoc comparisons did not show significant differences between groups (all *p* > .06) in spite of strong support for differences between the low and high groups (*BF* = 11.96) and moderate and high groups (*BF* = 19.48) in the Bayesian analysis.

7.4.3 Performance efficiency

Performance efficiency data were analysed using 3 (trait anxiety; low, moderate, high) x 2 (set size; three, four) x 2 (cognitive load; control, backwards counting) mixed

[16] Including self-reported depression as a covariate did not affect the pattern of significant findings (all non-significant *p* > .15). As with trait cognitive anxiety, including stress as a covariate removed the significant effect of set size (*p* = .073). The pattern of significant findings was also the same when excluding participants who reported currently taking medication for anxiety and/or depression, or those who did not indicate their medication status ($N_{EXCLUDED} = 5$; all non-significant *p* > .22).

factorial ANOVAs.[17] Mean performance efficiency data can be viewed in Table 7.5. Regarding trait cognitive anxiety, there were significant main effects of set size, $F(1, 65) = 18.93$, $MSE = .015$, $p < .001$, $n^2_p = .23$, $BF > 10,000$, and cognitive load, $F(1, 65) = 184.79$, $MSE = .022$, $p < .001$, $n^2_p = .74$, $BF > 10,000$. Importantly, there was no significant main effect of trait cognitive anxiety, nor any significant interactions (all $p > .72$, all $BF < 0.23$), an outcome supported by the multilevel analysis (all p involving anxiety > .31).

Table 7.5 Mean performance efficiency data (with SDs) for each trait cognitive and somatic anxiety group within each trial block.

	Control		**Cognitive load**	
	Set Size 3	**Set Size 4**	**Set Size 3**	**Set Size 4**
Trait cognitive anxiety				
Low	.75 (.16)	.67 (.21)	.48 (.20)	.42 (.15)
Moderate	.73 (.26)	.65 (.20)	.47 (.20)	.42 (.19)
High	.70 (.22)	.65 (.24)	.47 (.22)	.39 (.16)
Trait somatic anxiety				
Low	.73 (.19)	.66 (.19)	.51 (.18)	.44 (.14)
Moderate	.74 (.15)	.67 (.21)	.47 (.22)	.43 (.19)
High	.72 (.27)	.65 (.23)	.46 (.21)	.38 (.17)

[17] Efficiency was also operationalized as correct RT. Using this method, there was a significant effect of load, $p < .001$, suggesting efficiency was greater in the control condition. No other significant effects were observed on performance (set size $p > .050$, all other $p > .28$).

Regarding the main effects, Bonferroni-corrected pairwise comparisons indicated that efficiency was greater at set size three (*M* = .60, *SD* = .18), than at set size four, (*M* = .53 *SD* = .17), $p < .001$, *BF* = 1511, and in the control condition (*M* = .69, *SD* = .19) compared to the backwards counting condition (*M* = .44, *SD* = .18), $p < .001$, *BF* > 10,000. Further to this, there were no additional main effects or interactions observed for the analysis including trait somatic anxiety (all $p > .54$, all *BF* < 0.23) [18], which was again supported by the multilevel analysis (all relevant $p > .30$).

7.4.4 Serial position data

Further exploratory analyses were conducted to determine whether effects of anxiety on performance effectiveness were associated with the position in which memory items were presented in the memory sequence. Serial position data are available specifically for trials in which the test cue was presented in the initial memory sequence. Separate 3 (trait anxiety) x 2 (cognitive load condition) x 3 / 4 (serial position) ANOVAs were conducted within each set size.

At set size three, there were no significant effects relating to trait cognitive anxiety or somatic anxiety, or to serial position (all $p > .057$, all *BF* < 0.33). At set size four, there was a significant effect of serial position, $F(2.55, 166.07) = 7.46$, $MSE = .071$, $p < .001$, $n^2_p = .10$, *BF* = 994, but there were no significant effects relating to trait cognitive anxiety (all $p > .25$, all *BF* < 0.11). Regarding the main effect of serial position, Bonferroni-corrected pairwise comparisons indicated that performance at serial position 2 (*M* = .43, *SD* = .22) was worse than at positions 1 (*M* = .56, *SD* = .20),

[18] This was also the case when operationalising efficiency as correct RT.

p = .001, BF = 534, p 3 (M = .50, SD = .20), p = .025, BF = 3.06, and 4 (M = .56, SD = .24), p = .003, BF = 362. There were no other significant differences between serial positions (all $p > .20$, all $BF < 0.86$).

In the analysis involving trait somatic anxiety at set size four, there was again a significant effect of serial position that was strongly supported by the Bayesian analysis, $F(2.64, 195) = 8.27$, $MSE = .066$, $p < .001$, $n^2_p = .11$, $BF = 1072$. There was also a significant interaction between trait somatic anxiety group and serial position, $F(6, 195) = 2.33$, $MSE = .058$, $p = .034$, $n^2_p = .07$, $BF = 0.96$ (see Figure 7.3), however, note that there was no evidence in support of this interaction from the Bayesian analysis.

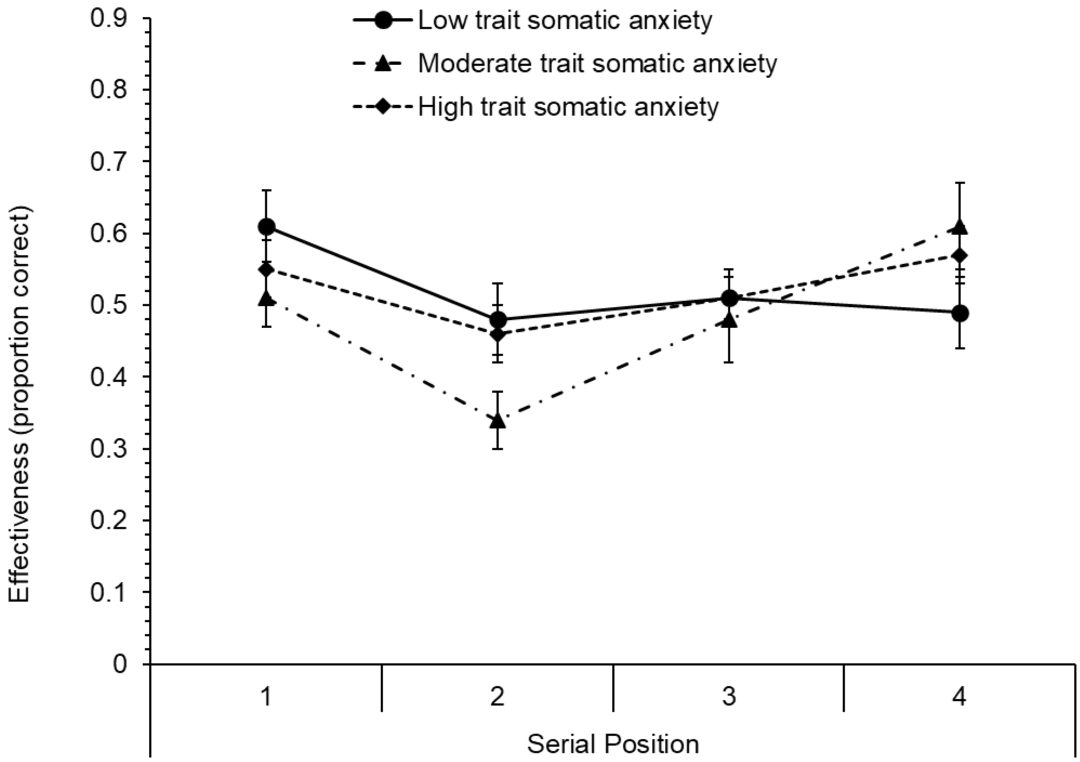

Figure 7.3 Serial position effectiveness data (with SDs) by trait somatic anxiety group at set size 4 in Study 4.

To follow up the trait somatic anxiety group x serial position interaction, repeated measures ANOVAs conducted within each anxiety group indicated that there were no significant effects of serial position in the low or high trait somatic anxiety groups (both $p > .11$, both $BF < 0.66$). However, there was a significant effect of serial position in the moderate trait somatic anxiety group, $F(3, 54) = 11.23$, $MSE = .021$, $p < .001$, $n^2_p = .38$, $BF = 2359$. Bonferroni-corrected pairwise comparisons indicated that performance was significantly lower at position 2 ($M = .34$, $SD = .18$) than at positions 1 ($M = .51$, $SD = .19$), $p = .002$, $BF = 39.39$, 3 ($M = .48$, $SD = .27$), $p = .028$, $BF = 4.11$, and 4 ($M = .61$, $SD = .28$), $p = .001$, $BF = 121$. Performance was also significantly lower at position 3 than at position 4, $p = .015$, $BF = 16.62$, with no significant differences between positions 1 and 3 and positions 1 and 4 (both $p > .66$, both $BF < 0.78$).

7.5 Discussion

The purpose of Study 4 was to assess the impact of trait anxiety on visual feature binding in working memory, while exploring the potential effects of cognitive load. The demand of the task was varied by manipulating set size (three or four items) and level of cognitive dual-task load (number repetition or backwards counting in threes). It was expected that while all participants would demonstrate poorer binding under high load as compared to the control condition, the high trait cognitive anxiety group would perform significantly less effectively and efficiently than the low and moderate groups. This was expected to be more easily observed when participants were asked to remember three, rather than four, items in memory, as there is evidence suggesting that highly anxious individuals will reach working memory capacity at three items, while less anxious individuals will reach working memory capacity at four items (Qi et al., 2014). Thus, memory in the high anxiety group would be taxed to a greater extent when three items were presented than memory in the low and moderate anxiety groups. The low and moderate groups would then see a greater drop in performance under load at set size four due to possessing increased, but still limited, memory capacity.

The key finding in the present study was that the effect of trait anxiety on performance was specific to the somatic dimension. The moderate and high trait somatic anxiety groups performed less effectively than the low group across both of the repeated measures task manipulations. Another important finding was the lack of a significant effect of trait cognitive anxiety on binding memory. Study 3 of this thesis found that moderate and high trait cognitive anxiety groups demonstrated reduced binding memory relative to shape memory, as a result of better shape memory at higher levels of trait cognitive anxiety. The present results support this outcome, with no effect of trait cognitive anxiety on performance effectiveness in tasks that exclusively tested binding ability. Furthermore, Spalding et al. (2021) failed to find an effect of trait cognitive anxiety on binding ability. Thus, the present study, as part of this wider range of findings, provides convincing evidence that trait cognitive anxiety is not associated with visual feature binding sufficiently to disrupt performance effectiveness or efficiency. However, the results of the present study support the results of Study 3 and Spalding et al. (2021), in that moderate and high levels of somatic anxiety were associated with reduced binding memory. It remains necessary, then, to determine why trait somatic anxiety is associated with binding memory. Notably, neither trait cognitive or somatic anxiety significantly interacted with cognitive load or set size in this study. Regarding set size, this result is surprising given that the interactive effects of trait somatic anxiety – when treated as a between-groups variable – observed in Study 3 were specifically at set size three, and not set size four. Regarding cognitive load, this appeared to affect all groups to a similar degree, and although performance varied with load, it was close to chance level (i.e., 50%), particularly at set size 4, suggesting the possibility that the task may have been too difficult and lacking in sensitivity to detect significant effects of interest regarding anxiety. This was particularly apparent when observing overall proportion correct data and false alarm data.

7.5.1 Trait somatic anxiety may demand attention

It is theorised that specifically cognitive facets of anxiety, primarily worry, demand attention (e.g., Eysenck et al., 2007). As discussed in Section 6.5.3, it is only possible to provide tentative explanations for the impacts of somatic, rather than cognitive, anxiety on performance observed here. This is due to the very limited previous research that has examined the relative impacts of cognitive and somatic anxiety on visual working memory. Thus this aspect of the present research programme is particularly novel. One possibility is that experiences of somatic anxiety also demand attention, and thus impair binding memory, which is particularly reliant on attention. Evidence from a study of the default mode network provides some initial support for this suggestion. Burdwood et al. (2016) examined default mode network (DMN) activity in 'rest blocks', interspersing performance of colour-word and emotion-word

Stroop tasks. They predicted that anxious apprehension – that is, anxious cognitions – would be associated with increased DMN activity, reflecting increased self-focused anxious thoughts. Simultaneously, they predicted that anxious arousal – i.e. somatic anxiety – would be associated with reduced activity, reflecting greater monitoring of the external environment. However, they found the inverse, with the data suggesting that anxious apprehension is associated with greater external focus, and anxious arousal with greater internal focus. Regarding this association between somatic anxiety and greater internal focus, the authors suggested that increased interoception – that is, awareness of physical bodily sensations – draws attention away from external stimuli. This outcome would fit with the results observed here. If trait somatic anxiety, as measured via self-report in the present study, reflects greater internal focus, it is possible that this occurs generally for individuals reporting higher levels of trait somatic anxiety and would therefore draw attention away from stimuli in the present task, in the way that trait cognitive anxiety is predicted to do. However, there is a need to further explore the relationship between somatic anxiety, interoception, and cognition in order to determine the mechanisms by which anxiety impacts on working memory.

Some researchers have taken steps towards understanding the impact of physiological anxious arousal on working memory. For example, some authors have reviewed evidence suggesting that anxious arousal shares greater overlap in neural systems with visuospatial working memory, and anxious apprehension with verbal working memory (e.g., Shackman et al., 2006; Vytal et al., 2013). These same studies have shown that anxious arousal may impair visuospatial working memory performance. However, they have done so when inducing situational anxiety in participants, thus increasing levels of anxious arousal during the task. The present results, it should be stated, do not indicate an incidental physiological anxious response as affecting performance. Instead, they suggest that a general propensity for increased somatic anxiety can affect visual working memory in the absence of a stressor or anxiety induction technique. This is further supported by the fact that self-reported state anxiety – either cognitive or somatic – did not predict performance in either Study 3 or the present study.

7.5.2 Trait somatic anxiety may reflect cognitive vulnerabilities

Another possible explanation for the effect of trait somatic anxiety is that the somatic subscale of the STICSA is in fact measuring a degree of cognitive vulnerability arising from anxious cognitions. Given that anxious cognitions at trait level give rise to anxious states that involve somatic anxious experiences (see Section 2.2.1), it is conceivable that high levels of trait somatic anxiety may reflect difficulties in regulating anxious cognitions, such that they become debilitating to individuals' attentional control. Jaiswal et al. (2018) compared change detection performance between a high trait anxiety/low mindfulness group and a low trait anxiety/high mindfulness group and found that the high anxiety/low mindfulness group were significantly less accurate and sensitive to detecting changes in a version of the Luck and Vogel (1997) change detection paradigm. This was inconsistent with previous literature where previously no negative behavioural effects of trait anxiety on performance of this task had been observed (e.g., Qi, Chen, et al., 2014; Qi, Ding, et al., 2014), or when trait social anxiety had improved performance (Moriya, 2018;

Moriya & Sugiura, 2012). Mindfulness refers to the ability to focus attention on the present moment while simultaneously reducing cognitive and emotional distress (Bishop et al., 2004). It is possible that the behavioural deficits observed by Jaiswal et al. were observed because the high anxiety group in their study reported low mindfulness and could not adequately manage their feelings of anxiety 'in the moment'. Applying this to the present findings, trait somatic anxiety may similarly reflect the inability to manage cognitive experiences of anxiety, hence these participants report more frequently experiencing somatic anxiety. Indeed, there is evidence that greater anxious arousal is the product of high levels of anxiety sensitivity – i.e., cognitive fears of anxiety – and low mindfulness (Vujanovic et al., 2007), although that study did not measure cognitive outcomes. As noted, this suggestion is tentative and should be considered with key limitations in mind. For one, Jaiswal et al. (2018) did not compare performance between groups reporting all combinations of anxiety and mindfulness levels (i.e., they did not include high anxiety/high mindfulness or low anxiety/low mindfulness groups in their design). As a result, it is not possible to state with certainty that reduced mindfulness in interaction with higher anxiety levels was the reason for the observed performance deficit. Furthermore, the present study demonstrated effects of trait anxiety, but not state anxiety, which would suggest that levels of anxiety during the task itself did not demand attention. A caveat regarding the non-significant effects of state anxiety, though, is that state anxiety was only measured prior to the experimental task. State anxiety, by definition, is dynamic and fluctuates depending on stressors specific to a given situation. If, for example, participants found the task stressful in itself and this increased their anxiety, the initial measure of state anxiety would not have reflected this. Therefore, it would be useful to modify the approach to studying the effects of anxiety on working memory in future research by measuring state anxiety over the course of a task. This can be achieved via physiological measures such as skin conductance or heart-rate monitoring, which have previously been employed to measure anxiety in test situations (see Roos et al., 2020 for a review). Neural mapping, for example, via magnetic resonance imaging, has also been used to assess differences in activation between trait anxiety and state anxiety when participants are in a resting state (Burdwood et al., 2016; Saviola et al., 2020). It is also possible to devise or adapt self-report measures that can be employed throughout completion of a task, for comparison of subjective and objective anxious responses (Edwards et al., 2006; Edwards et al., 2010)

It is also possible that the trait somatic scale of the STICSA is a better measure of anxiety sensitivity, and therefore susceptibility to cognitive fears of anxiety, overall. Evidence has indeed shown that trait anxiety is related to the monitoring of bodily signals (Ginzburg et al., 2014), with increased body vigilance observed in panic disorder and GAD patients (Olatunji et al., 2010). It is therefore of particular interest to further explore the impacts of trait somatic anxiety on visual working memory, and indeed wider working memory performance, in relation to these other constructs. Detailed consideration of these is provided in the general discussion (see Section 8.5.1)

However, it is important to highlight that, in attempting to determine a specific causal factor regarding the effect of trait somatic anxiety on performance, there is an additional difficulty in assuming that high levels of trait somatic anxiety reflect diminished regulation of anxious cognitions. In the present study, there were almost twice as many participants who reported high trait somatic anxiety as there were participants who reported high trait cognitive anxiety. It would be useful to further investigate the extent to which mindfulness – or lack thereof - may have contributed to a greater number of participants reporting high trait somatic anxiety scores. As noted by Roos et al. (2020), somatic symptoms of anxiety are difficult to voluntarily suppress, and self-report measures of anxiety are subject to social desirability biases. Participants may have more readily reported high trait somatic anxiety than trait cognitive anxiety. Employing subjective self-report measures of anxiety as well as physiological and neural measures, as described above in this section, would help to better clarify the potential role of metacognitive factors (e.g., being able to accurately report one's own anxious thoughts as compared to physiological sensations) in accurately measuring anxiety. Certainly, though, the sound reliability and validity of the State-Trait Inventory for Cognitive and Somatic Anxiety (Ree et al., 2008), is increasingly well documented in the literature (see Section 3.2.3) and was an appropriate means of assessing anxiety using self-report, which is a widely used method of measuring anxiety.

7.5.3 Trait anxiety and memory efficiency

The absence of a significant effect of trait cognitive and somatic anxiety on binding efficiency in the present study is consistent with the results of Study 3. In Study 3, the interaction between trait cognitive anxiety and memory type in predicting performance efficiency was a result of the moderate and high trait cognitive anxiety demonstrating lower binding memory efficiency compared to shape memory efficiency, with no difference observed in the low anxiety group. Given that there was no comparison between shape and binding memory in this study, the present results provide further indication that moderate and high trait cognitive anxiety scorers may demonstrate reduced binding efficiency, but only in comparison to shape efficiency. That is, they do not demonstrate poorer binding efficiency compared to those reporting low trait cognitive anxiety. The interaction between trait somatic anxiety and memory type also followed this pattern, though specifically within Study 3. Therefore, the present study presents further, albeit indirect, evidence that binding efficiency deficits observed at moderate-high levels of trait anxiety are driven by a difference in the ability to efficiently bind objects compared to recalling individual features, rather than an overall difficulty in binding relative to low levels of trait cognitive anxiety. The results support a range of previous evidence from behavioural studies of attentional shifting and inhibition (e.g., Edwards et al., 2015; Edwards et al., 2017; see also Section 2.4.3) and neurological studies of processing efficiency in attention and working memory tasks (e.g., Bishop, 2009; Fales, 2008; see also Sections 2.5.2 & 2.5.3) suggesting reduced efficiency at higher levels of trait anxiety. Importantly, the present results come with the additional finding that efficiency may be driven by deficits occurring within-groups, subject to changes in task demand, as opposed to between-groups differences.

7.5.4 Trait anxiety and cognitive load

Neither trait cognitive nor somatic anxiety interacted with cognitive load. While the potential reasons for a lack of an effect of trait cognitive anxiety on performance are provided in the previous sections, it is important to determine why cognitive load did not vary performance depending on somatic anxiety levels. In the first instance, the results could be described as unequivocal, as there was neither evidence for a benefit or detriment to performance at higher levels of anxiety under cognitive load. If load was beneficial to cognitive performance at higher levels of anxiety (e.g., Basanovic et al., 2018; Najmi et al., 2014), an interaction would have been observed wherein the moderate and high trait somatic anxiety groups performed less effectively in the control condition, but not the load condition. If load had an additional negative effect on cognitive performance at higher levels of anxiety (e.g., Berggren 2012, 2013; Judah et al., 2013), the moderate and high trait somatic anxiety groups compared to the low trait somatic anxiety group would have exhibited a significantly greater reduction in performance under load than they did in the control condition. It would appear that the effects of trait somatic anxiety on visual feature binding are sufficiently robust that they serve as an extra demand on cognitive resources above and beyond those of a concurrent task, rather than exacerbating any effects of the dual-task load. This is the case as if the additional cognitive load was more debilitating than the load of anxiety, it would have been unlikely that any group differences in performance would emerge or would only have appeared in the control condition. An explanation for the observed effect of trait somatic anxiety on performance could be that high (or indeed moderate, as observed in this study) trait somatic anxiety is reflective of anxiety occupying an individual's executive resources beyond a manageable threshold, to the degree that it is detrimental to cognitive function.

7.5.5 Cognitive load and serial position

The serial position data obtained in this study do not reflect clear support for ACT (Eysenck et al., 2007). Regarding trait cognitive anxiety, the lack of a significant effect of anxiety on overall performance extended to a lack of a significant interaction between trait anxiety and serial position. As with the previous studies reported in this thesis, it does not appear as though anxious cognitions serve simply as an additional load on executive resources that disrupts visual working memory. If this were the case, the high trait cognitive anxiety group would have performed worse, primarily at earlier positions in the memory sequence, than the lower anxiety groups would. This would reflect the effect of a dual-task load observed in previous studies examining sequential binding independent of anxiety (Allen et al., 2009; 2014; 2017; Hu et al., 2014; Hu et al., 2016; Karlsen et al., 2010).

The results with respect to ACT (Eysenck et al., 2007) are even less clear when examining the effect of trait somatic anxiety on serial position data. Here, the moderate trait somatic anxiety group were significantly poorer at position two than at positions one, three, and four, indicating a particular difficulty maintaining the item that is most prone to being overwritten. This reflected the general performance deficit observed in this group when compared to the low trait somatic anxiety group. It is however important to highlight that this effect was observed in the present study, but not in Study 3, which also investigated sequential binding. This is likely because the present study only assessed binding memory, while Study 3 assessed both shape and binding memory. It could be the case that in Study 3 there were not enough binding trials to demonstrate a significant effect of anxiety on serial position performance. In the present study, participants effectively completed twice as many binding trials at each set size. Based on these findings, there is a clear need to clarify whether the negative impact of moderate trait somatic anxiety can be observed consistently, as this finding is not consistent with research that has demonstrated linear relationships between trait somatic anxiety and visual working memory (Spalding et al., 2021; Study 3 of this thesis). It should however be noted that the interaction between trait somatic anxiety and serial position observed in the present study was not supported by the Bayesian analysis, suggesting that the finding may not be robust when also considering previous research, as well as Study 3, reported in Chapter 6.

Regarding serial position more generally, the present results failed to find support for key findings observed previously in the visual working memory literature. Namely, evidence for a pronounced recency effect in binding memory, and reduction in memory for early sequence items arising from an additional cognitive load. Typically, the literature has demonstrated that the final item in a memory sequence is relatively protected from adverse effects of an additional concurrent task load, due to the fact that this item relies on perceptual, rather than executive attention (Hitch et al., 2020). In the present study, although the serial position effect was observed, there was only a main effect of cognitive load, suggesting that the final serial position was impacted by the additional demands of the concurrent backwards counting task to a similar extent as the other items. This occurred across both memory set sizes. Furthermore, the main effect of serial position only appeared in the present study at set size four, wherein memory for serial position 2 was significantly lower than all other serial positions. This finding is consistent with those reported in Study 3 (Chapter 6), suggesting a particular difficulty for participants, regardless of anxiety level, to successfully maintain bindings at this position in the face of proactive and retroactive interference.

7.5.6 Limitations and future directions

A suggestion for future research made by Spalding et al. (2021) is particularly relevant to the present study. In that paper, we highlighted that previous research demonstrating a negative effect of anxiety on visual working memory performance (e.g., Berggren et al., 2017; Jaiswal et al., 2018) did not employ *any* dual-task manipulations, i.e. the visual working memory task was performed without additional load or articulatory suppression. It is possible that further effects of anxiety in Study 3 and the present study may have been limited due to the use of articulatory suppression as either the default or control task condition. The experience of worry inherent to anxiety has previously been suggested to serve as an additional cognitive load in working memory tasks, taking the form of negative internal self-statements that engage the phonological loop and central executive (e.g., Hirsch & Mathews, 2012; Markham & Darke, 1991; Rapee, 1993; Wells, 1995). With higher cognitive load previously suggested to reduce anxiety levels (e.g., King & Schaefer, 2010; Vytal et al., 2012), effects of worry – that is, anxious cognitions – may have been masked and/or reduced due to the secondary verbal task. That is, the load imposed across trait cognitive anxiety levels becomes equivalent as it comes from the concurrent backwards counting or number repetition task, rather than anxiety itself, and/or reduces the effect of anxiety on cognition by masking or distracting from anxiety-related experiences. Despite the possible role of articulation, it should be highlighted that the approach adopted in the present study follows most previous literature using the sequential, cued recall binding paradigm in controlling for articulation (e.g., Hu et al., 2014; Hu et al., 2016). Nonetheless, a future study examining the effects of anxiety on visual working memory and the possible interaction with load would benefit from comparing conditions with no dual-task as well as varying levels of load (e.g., comparing a control condition involving active subvocalization with concurrent number repetition, *1*-back and/or *3*-back conditions).

There are also inconsistencies in the present results as compared with the similar results obtained by Spalding et al. (2021) and in Study 3 (Chapter 6). Spalding et al. (2021, Study 2) found a negative linear association between trait somatic anxiety and binding effectiveness (proportion of correct responses) as well as binding efficiency (response times in trials where participants responded correctly). Study 3 of this thesis also demonstrated a negative linear relationship between somatic anxiety and binding effectiveness. The present study demonstrated between-groups differences in performance effectiveness, however moderate trait somatic anxiety was also associated with reduced binding performance compared to the low group. In this case, the effect occurred across set size and load conditions, and the relationship was nonlinear. Bringing these finding together, there is a clear need to reconcile the differences between these outcomes. Data collection for the present study was cut short, as mentioned in Section 7.3.1, which may have impacted on the overall pattern of results observed here because, as can be observed in Section 6.3.1 and 7.3.1, Study 4 was underpowered relative to Study 3. Although, it should also be clarified that the range and mean values of anxiety scores within the trait cognitive and somatic anxiety groups were similar across studies. Future research could usefully examine the difference in performance between individuals of varying trait somatic anxiety levels across simultaneous and sequential binding conditions, and potentially across set size, independent of cognitive load manipulations or differences in memory type (i.e., shape or binding). This research would help to determine the extent to which stimulus presentation format and specific anxiety levels impacts results.

7.6 Chapter summary

This chapter reported the findings of Study 4, which examined the impact of trait anxiety on binding memory in a sequential binding task of varying memory load (set size), and whether this relationship was affected by additional cognitive load. Based on the present findings, it would appear that trait somatic anxiety has a negative impact on visual feature binding. However, no evidence was found for an effect of trait cognitive anxiety on binding performance. In summarising Study 3 (see Section 6.6) it was suggested that the binding deficit observed with moderate and high anxiety supports Attentional Control Theory (Eysenck et al., 2007) in that greater perceptual demand is harder to process as anxiety increases. These findings suggest this difficulty may be specific to trait somatic anxiety as measured by the STICSA (Ree et al., 2008). There are several possibilities as to why trait somatic anxiety impacts negatively on visual feature binding. High trait somatic anxiety may reflect a greater influence of cognitive anxious experiences, may demand attention itself, or the STICSA somatic subscale may be a better measure of interacting underlying cognitive processes in anxiety, or a 'purer' anxiety measure. Higher trait somatic anxiety may also reflect a greater monitoring of, and therefore attentional focus on, bodily experiences. Further work is required to determine the mechanisms underlying the relationship between trait somatic anxiety and visual working memory, which appears to be an increasingly robust association.

8 General Discussion

8.1 Chapter overview

The aim of this thesis was to provide a better understanding of the impacts of trait anxiety on visual working memory performance. Specifically, the main objective was to apply the general principles of Eysenck et al.'s (2007) Attentional Control Theory (ACT) of anxiety to current visual working memory paradigms, in order to determine how anxiety may influence the contents and capacity of working memory via effects on attentional control. The chapter will begin with a summary of the key findings with respect to anxiety and the choice of experimental methods used to achieve the stated research objectives. The findings of each study will then be considered together – again focusing on those relating to anxiety in the first instance – and specific conclusions will be drawn for understanding of the relationship between anxiety and cognition. The chapter will also include discussion on how future research may develop upon the present work, and where present limitations can be most usefully addressed. Consideration will also be given to how the present results can inform the understanding of working memory more generally. The main argument made with respect to the overall pattern of findings is that anxiety does appear to be associated with reduced visual working memory performance, but this is not clearly explained as originally predicted, based on the main principles of ACT. Instead, variations in working memory capacity, task demand, and effortful processing associated with anxiety in recent research may provide important insight into the nature of the relationship between anxiety and cognitive performance. It will also be argued that a major contribution of the present studies is the finding that it is not simply trait cognitive anxiety, but also trait somatic anxiety, that can influence visual working memory performance. This finding adds to a relatively small but growing literature base investigating the comparative impact of these dimensions of anxiety on cognition. Finally, consideration will be given to implications for models of working memory independent of effects of emotion, drawing on the pattern of findings regarding the experimental manipulations used across the present studies. Overall, it will be argued that this thesis can make a unique and impactful contribution to the literature regarding the effects of anxiety on cognition, particularly visual working memory.

8.2 Summary of key findings

Each of the four studies reported in this thesis involved a different manipulation of attention. Studies 1 and 2 were planned in unison in order to assess, respectively, the effects of anxiety on executive and perceptual attention, and subsequent outcomes for visual working memory. Studies 1 and 2 each involved a visual feature binding task, based on the earlier work of Hu et al. (2014; 2016; see Sections 1.4.1 & 3.5.1) in which participants were asked to remember sequences of four items, with a cued recall test phase. Study 1 encouraged participants to engage top-down control of attention to prioritise specific items in memory. Participants reporting higher levels of trait cognitive anxiety were expected to have more difficulty prioritising items in memory, such that their recall of stimuli presented earlier in the memory sequence would be significantly poorer than that of later items, because earlier items require maintenance via executive attention (Hitch et al., 2020). In contrast, Study 2 introduced a perceptual distractor in the form of a visual suffix (see Section 3.5.1) in order to engage bottom-up attention. It was expected that participants who reported higher levels of trait cognitive anxiety would demonstrate greater visual suffix interference, based on previous evidence that attention is more easily captured by irrelevant stimuli in individuals who report greater levels of anxiety (e.g., Moser et al., 2012; Sadeh & Bredemeier, 2011). Individuals who report higher levels of anxiety also appear to have less ability to filter distractors from working memory (Qi, Ding et al., 2014). Participants in Study 2 who reported higher levels of trait cognitive anxiety were expected to demonstrate greater visual suffix interference, which would be observed as a greater reduction in performance for the final item in the memory sequence, which is the item is most susceptible to perceptual interference. Contrary to predictions, there were no significant effects of anxiety on visual feature binding memory observed across Studies 1 and 2.

Studies 3 and 4 were intended to address the potential methodological factors that may have obscured significant effects of anxiety on visual working performance in the first two studies, if indeed these effects exist. Each involved a change detection response method in the sequential binding task, which has previously been used in the general visual binding literature (e.g., Allen et al., 2006, 2014; Brown & Brockmole, 2010; Ueno et al., 2011; Wheeler & Treisman, 2002) and also recently to demonstrate effects of anxiety on visual working memory (Moreno et al., 2015; Spalding et al., 2021). Each study included comparisons of memory performance for sets of either three or four items, because there is evidence that the visual working memory capacity of individuals reporting high levels of trait anxiety is three items (Qi, Chen et al., 2014). In Study 3, memory was tested for both individual features (shapes) and feature conjunctions (colour-shape bindings), as maintaining bindings in attentional focus is thought to be particularly attentionally demanding compared to maintaining individual features when they are presented sequentially (Allen et al., 2006; Brown & Brockmole 2010; Brown et al., 2017). It was predicted that higher trait cognitive anxiety would be associated with reduced binding memory compared to shape memory, specifically when the memory set consisted of three rather than four items, due to the potential capacity limitations associated with trait anxiety. However, this approach instead demonstrated that increased levels of trait cognitive anxiety may actually improve less-demanding shape memory, causing a binding deficit. More in line with the predictions, moderate and high trait somatic anxiety were also associated with a deficit in binding memory compared to shape memory, a finding observed specifically when the memory load was lower, that is, a load of three items. Further to this, trait somatic anxiety was negatively and linearly associated with binding memory overall, suggesting that higher levels of anxiety on this particular dimension contributes to poorer binding ability. Finally, in Study 4, sequential binding performance was compared under conditions of low cognitive load (concurrent number repetition) and high load (concurrent backwards counting). Here, moderate and high anxiety trait somatic anxiety groups performed significantly worse than a low trait somatic anxiety group in binding memory, with no differences associated with trait cognitive groups, set size, or cognitive load. This outcome supported conclusions drawn from Study 3, that: a) relative to lower levels of trait cognitive anxiety, binding deficits at higher levels of trait cognitive anxiety are driven by improved shape memory, not impaired binding memory, and b) binding deficits in those with moderate and high trait somatic anxiety are driven by impaired binding memory as opposed to improved shape memory.

8.3 Attentional Control Theory and visual working memory

Considering the results of the present studies together, it is appropriate to first discuss the implications of the findings for visual working memory specifically in the context of Attentional Control Theory (Eysenck et al., 2007), which was the main theory informing the hypotheses. There was limited support for the general prediction of ACT that anxiety impacts top-down and bottom-up attention to predict subsequent cognitive performance. This conclusion is drawn from both the specific task manipulations used in each study, and a general pattern in the serial position data obtained across studies. However, the results did provide insight into the mechanisms by which varying experiences of anxiety – cognitive and/or somatic – can affect visual working memory, and the specific effects these may have on performance effectiveness and efficiency.

8.3.1 Top-down and bottom-up attention in anxiety

Looking to the serial position data, a robust finding across all four of the present studies was that there was not a significant interaction between trait anxiety and serial position. The rationale for Studies 1 and 2 is particularly relevant in this case. The visual feature binding paradigm has previously been used to demonstrate that the most recently presented item in a memory sequence is significantly better remembered that the items that precede it, and that this advantage occurs to a greater extent for bindings rather than individual features (Allen et al., 2006; Brown & Brockmole 2010; Brown et al., 2017). The use of the serial binding paradigm in these studies was intended to assess the relative impacts of the executive and perceptual attentional systems on the subsequent content of visual working memory. Memory for items presented at specific points within a sequence, over a period of less than one second, is differentially affected by manipulations of these attentional systems. The role of executive attention in sequential memory has typically been assessed using dual-task paradigms. An additional cognitive load (often, performance of a concurrent backwards counting task) has been shown to disrupt both feature and binding memory at earlier sequential positions (Allen et al., 2009, 2014, 2017; Hu et al., 2014, 2016; Karlsen et al., 2010). This disruption is likely the result of a retroactive interference effect whereby earlier items are overwritten by subsequently presented items, with executive attention required to maintain earlier items in this context. Based on this, the results provide no indication that anxiety negatively impacts visual working memory specifically by limiting top-down attention in a manner equivalent to an additional cognitive load. Across all studies, there was no decline in performance at the first position in the memory sequence associated with either trait cognitive or somatic anxiety. The moderate trait somatic anxiety group did exhibit a significant drop in performance at serial position 2 in Study 4, but this drop was only for a four-item array and was not demonstrated across studies. Furthermore, when introducing an additional cognitive load in Study 4, all groups were similarly negatively affected by this load across all serial positions. The serial position data also indicate that highly anxious individuals did not show enhanced bottom-up processing at the expense of top-down processing. Had there been such an enhancement, higher anxiety would have been associated with better performance at the final serial position and worse performance at earlier positions, which was not demonstrated here. Thus, alternative explanations must be provided to explain the effects of anxiety on working memory observed in Studies 3 and 4 as well as in the wider literature. Some potential explanations are provided in the following sections of this chapter.

8.3.2 Processing efficiency and effectiveness

An important assumption made by Eysenck et al. (2007) is that anxiety will more reliably affect performance efficiency rather than performance effectiveness. This assumption was primarily supported by evidence from studies assessing effects of anxiety on attentional shifting and inhibition, with less focus on working memory outcomes (Section 2.4.3). Regarding the present findings, a reliable effect of trait somatic anxiety was found on participants' proportion of correct responses in binding tasks in Studies 3 and 4. This result suggests that anxiety can have an observable negative effect on behavioural performance effectiveness. Although effects of anxiety on performance effectiveness are less consistent in measures of attention (see Section 2.4.3), the results of Studies 3 and 4 are in line with a growing number of other studies demonstrating that anxiety can impact effectiveness in working memory tasks (Berggren 2017, 2020; Jaiswal et al., 2018; Sari et al., 2017; Spalding et al., 2021). Furthermore, trait cognitive anxiety was associated with a greater proportion of correct responses for individual feature memory in Study 3. Therefore, it is necessary to determine the potential methodological factors that allowed these behavioural differences to emerge.

Regarding effects of anxiety on processing efficiency across the present studies, the results are arguably quite illuminating with respect to the conditions under which these effects may emerge in working memory. Only Studies 3 and 4 included measures of efficiency, and the results varied in each study. Effects of anxiety on performance efficiency were only observed in Study 3, in which shape and binding memory were compared, and not in Study 4, in which only binding memory was tested under varying cognitive load. The results suggested that individuals reporting moderate to high levels of trait cognitive and somatic anxiety were significantly more efficient in remembering shapes than in remembering bindings, a result driven by enhanced shape memory efficiency rather than impaired binding memory efficiency. That is, these groups demonstrated a deficit in binding efficiency as compared to shape memory efficiency, rather than an efficiency deficit in comparison to those with lower anxiety. This result suggests that both trait cognitive and somatic anxiety can improve the efficiency with which individuals perform visual working memory tasks when the demands are relatively low (probe recognition of an individual object feature), but also that they experience greater difficulty in binding efficiently, by comparison. With respect to ACT (Eysenck et al., 2007), it could be suggested that these results reflect to some degree an impaired ability to maintain and differentiate feature conjunctions at a stage following initial perceptual attention. Eysenck et al. (2007) suggest that perceptual attention is enhanced at higher levels of anxiety, which is possibly reflected in better memory for basic features in the present results. The explanation from the ACT perspective appears relatively straightforward – a task that requires no further elaborative processing beyond recognising an individual feature is not likely to draw significantly upon further resources, for example, executive attention, and therefore greater external vigilance associated with anxiety can improve performance. This interpretation also appears to apply to performance effectiveness at higher levels of trait cognitive anxiety. However, when binding is required, individuals who report higher levels of anxiety appear to struggle to maintain the level of performance observed for individual features, presumably due to the additional processing and maintenance requirements of binding in sequential tasks. By comparison, while individuals reporting lower levels of anxiety do not demonstrate similarly high levels of shape memory efficiency, their performance between shape and binding conditions is more stable. Regarding trait somatic anxiety in this context, it would appear that these effects are limited to smaller working memory loads (three items rather than four), suggesting an association between trait somatic anxiety and working memory capacity that was not apparent when examining trait cognitive anxiety. Importantly, the results of Study 4, in which no efficiency deficits were demonstrated at higher anxiety, further supports the view that the interaction observed in Study 3 was driven by improved shape memory. As shape memory was not tested in Study 4, it follows that there would not be an observable effect of anxiety on efficiency outside of an interaction with different types of memory being tested. However, as memory for individual features was only compared with feature binding in one of these studies, further comparisons of performance across memory types will be needed in future to confirm the reliability of this outcome.

8.3.3 Anxiety, worry and cognition

In seeking to test the application of ACT (Eysenck et al., 2007) to visual working memory, the focus of the present studies was also on the effects of trait cognitive anxiety on task performance. Although there are few predictions regarding specific dimensions of anxiety included in ACT, it was assumed that anxiety occupies attention through worry, that is, anxious cognitions which are typically subvocal (e.g., Hirsch &

Mathews, 2012; Rapee, 1993; Wells, 1995). Subvocalised worries were assumed to engage the phonological loop. In turn, limited domain-general executive resources are thought to be occupied while engaging with worry. In the present research, it was therefore expected that reduced executive resources arising from anxious cognitions would negatively affect performance in visual binding tasks requiring the central executive. As observed in Studies 3 and 4, however, trait somatic anxiety was more strongly associated with visual working memory in the direction predicted, resulting in lower accuracy and decreased efficiency in visual feature binding, while trait cognitive anxiety was associated with improved feature memory accuracy. To briefly speak to the implications of this outcome for ACT, it would firstly appear that anxious cognitions do not simply engage limited executive resources at the expense of moment-to-moment cognitive functioning. In fact, as suggested in Section 6.5.2., it is possible that cognitive anxiety may drive individuals to more closely monitor the environment (e.g., Moriya & Sugiura, 2012) or direct their attention outward (Burdwood et al., 2016), allowing them to better remember basic visual stimuli (i.e. individual features; see also Section 8.3.2 & Section 8.6).

8.4 Anxiety, working memory capacity, and task demand

As noted in Section 8.2 above, there were key methodological considerations undertaken in designing Studies 3 and 4 that appeared to be decisive in influencing the overall pattern of findings observed across this thesis. The method by which participants responded was changed from cued recall to change detection using a single memory probe, and performance was compared across varying memory loads. These specific manipulations seemed to implicate effects of both trait cognitive and somatic anxiety on visual working memory ability, where none had thus far been observed within the present research. Taken in unison, the non-significant findings regarding anxiety in Studies 1 and 2, and the significant effects of anxiety in Studies 3 and 4, may indicate interacting roles of task demand and working memory capacity for better understanding the relationship between anxiety and visual working memory.

Initial evidence came from Study 3 that effects of anxiety on binding performance were more likely to be observed at lower memory loads, or were driven by reduced task demand. Moderate and high trait somatic anxiety groups demonstrated a binding deficit, specifically for memory arrays of three rather than four items. However, this latter finding was more nuanced, as trait somatic anxiety - when considered as a continuous variable - was negatively and linearly associated with binding memory overall. Therefore, while the use of three-item arrays appeared necessary to observe differences between memory types, it appeared that differences between individuals of varying trait somatic anxiety levels could be observed for binding memory across set sizes. This was further supported by the results of Study 4, where the moderate and high trait somatic anxiety groups performed significantly worse than the low group, regardless of set size or level of additional cognitive load.

It was initially predicted that anxiety would be associated with performance deficits for binding and under increased load specifically for memory arrays of three items. These hypotheses were based on previous evidence that anxiety is associated with lower working memory capacity (Qi, Chen et al., 2014). The hypotheses were also informed by previous behavioural evidence that anxiety affects working memory specifically for memory arrays of three items (Moreno et al., 2015; Spalding et al., 2021). Finally, the hypotheses were also informed by the non-significant results in Studies 1 and 2, which exclusively used four-item arrays. As this result was only partially supported in Study 3, conclusions can be drawn as to the specific factor that influenced the change from non-significant effects of anxiety in Studies 1 and 2 to significant effects in Studies 3 and 4. The particular factor that would appear to be responsible is the change in response method used between studies. In Studies 1 and 2, participants were required to orally recall a specific cued feature from memory. This method of recall would require them to 'search' and identify a correct response from amongst the presented memory array, or wider pool of potential memory features. In Studies 3 and 4, responses were based on nondeclarative recognition, via keypress. That is, there was no need to identify specific memoranda, and it could be presumed that responses are made more quickly as a result. Logie et al. (2009) have suggested that cued recall relies additionally on verbal memory for responses, which may facilitate long-term learning to a greater extent than change detection. Other studies employing visual reconstruction responses rather than change detection also show that the learning of visual features is enhanced by more elaborative processing (Brady et al., 2009; Shimi & Logie, 2019). However, if verbal memory is also required in cued recall, then cued recall may be a less pure measure of visual working memory, and involves different processes than those involved in making same-different judgements. Memory retrieval has previously been conceptualised as occurring either through explicit recollection of a stimulus, or implicit familiarity with a stimulus. Explicit recollection – more so than implicit familiarity – has been shown to be reduced when attention is divided or directed elsewhere (e.g. Jacoby, 1999; Symanski & MacLeod, 1996). This would suggest that binding in a recognition task as opposed to cued recall, despite also involving sequential presentation, is not as susceptible to being overwritten as new information is attended to. Thus, all participants may have found the task equally difficult to perform in Studies 1 and 2 with the concurrent demands of sequential presentation and declarative binding memory, whilst being unable to verbally encode stimuli due to articulatory suppression.

Ultimately, when comparing the relative contribution of memory load and response method in determining the significance of results across studies, it would appear that the change in response methods was most influential. However, it would be beneficial to continue assessing the effects of memory load in future research, as the results are not entirely inconsistent with the view that individuals who experience greater levels of anxiety may demonstrate a lower working memory capacity. This applies, at least, to the results from the trait somatic analyses. It appears that individuals reporting lower levels of trait somatic anxiety are more capable of performing effectively across loads of three and four items. Therefore, comparing binding performance with memory loads of three and four items with performance in even greater set sizes in future would potentially indicate the exact threshold at which a visual working memory task becomes equally difficult for all participants. This would also allow for the reliability of the effect of trait somatic anxiety on binding memory to be better determined.

8.4.1 Anxiety and task demand: the role of effortful cognitive processing

As discussed in Section 2.3.4, anxiety has been associated with motivation to perform in cognitive tasks, with the assumption that tasks requiring more effortful processing encourage highly anxious individuals to expend greater effort in order to improve their performance (e.g., Berggren & Derakshan, 2013; Eysenck & Calvo, 1992; Eysenck et al., 2007). The level of engagement involved in performing the working memory tasks between the studies of this thesis may help to explain why significant effects of anxiety were observed in Studies 3 and 4, but not Studies 1 and 2. In Studies 1 and 2, the task may have been more difficult, requiring greater levels of processing when formulating trial responses. However, there is also evidence from the anxiety literature that may implicate a role of effort encouraged by the response methods used across studies in influencing the significance of results across studies.

Hayes et al. (2009) have tested two key hypotheses with respect to ACT (Eysenck et al., 2007) that implicate the role of effort in cognitive performance. They asked participants classified as either 'Low Anxiety' or 'High Anxiety' to assign faces to specific categories based either on either specific combinations of features (a capacity dependent condition) or resemblance (a capacity independent condition). In some conditions, categories were defined indirectly via concurrent pleasant/unpleasant sounds (an incidental learning condition), and in others, participants were directed to learn the specific categories (an intentional learning condition). Firstly, they predicted that as capacity demands of the task increased, so too would anxiety-related performance deficits become more apparent. Secondly, they predicted that as a task requires greater effortful goal-directed attentional control, so to would anxiety related performance deficits become less apparent. This is because the highly anxious participants' performance effectiveness would improve as more effort was expended on the task. They found support for these hypotheses, with results showing that high anxiety only negatively affected performance in the task when learning was incidental rather than effortful, and more so for capacity-dependent rather than capacity-independent learning. Thus, a task that requires effortful processing may not be suitable for demonstrating differences in performance arising from anxiety, even if that task is particularly taxing on working memory, as in Studies 1 and 2. However, if the task is capacity dependent, but processing is less effortful, then effects may be observable, as in Studies 3 and 4. Thus, tasks in which there is less motivation to expend effort in processing may better reflect consistent, everyday cognitive effects of anxiety in response to tasks requiring little to moderate effortful engagement. Berggren and Derakshan (2013) have also noted that Hayes et al.'s findings follows evidence of a positive correlation between anxiety and subjective cognitive failures in everyday tasks (Broadbent et al., 1982). To interpret the studies reported in Chapters 4-7 in this specific context, anxiety may not have affected performance in Studies 1 and 2 as there was increased effortful processing required in making responses due to the cued recall response component. By comparison, in Studies 3 and 4, where probe recognition responses required less effortful processing, significant effects of anxiety could be observed. Regarding trait cognitive anxiety, advantages of increased perceptual attention may have been observed. Higher levels were potentially associated with better shape memory performance because features require less elaborative processing than binding, but binding still required less effort in probe recognition than in cued recall. Regarding trait somatic anxiety, the significant negative effect of anxiety on binding would therefore be a result of binding being a sufficiently difficult process to tax visual working memory, but less effort needed to be expended in the change detection versions of the task. Therefore, performance deficits were able to be observed.

8.4.2 Effortful processing or overly demanding tasks?

It should be reiterated that, although the above Section 8.4.1 provides an example of conditions under which effects of anxiety on working memory may be masked, the explanations for the mechanisms behind these outcomes are potentially separable, a possibility that would be valuable to explore in future. On one hand, it is possible that effortful processing helps to improve anxious individuals' performance in cognitive tasks by increasing the effort they expend in order to perform well, bringing these participants level in performance with individuals reporting lower anxiety in Studies 1 and 2. On the other hand, however, a task such as the cued recall sequential binding task used in Studies 1 and 2, which requires greater processing, may in itself be more difficult for all participants. In this scenario, the task may be difficult to the degree that any potential anxiety-driven deficits are masked by an overall reduction in performance across the whole sample. The problem in identifying the most likely explanation for the lack of group differences in the cued recall tasks can be illustrated by the results of Studies 1 and 2. In Study 1, effortful processing was encouraged to an even greater extent as participants were given instructions to attend towards specific items in the memory sequence. It therefore may have been expected, based on the discussion in this section, that those who reported higher anxiety would show a deficit in the control condition – where no prioritisation was encouraged – as compared to the prioritisation conditions, as there was less effortful processing. However, there were no between-groups differences in any condition. Thus, this result supports the view that the task was, generally, too difficult to allow for significant between-groups differences to emerge. However, in Study 2, suffix presentation was sufficient to further decrease performance as compared to the control condition in which no suffixes were presented, suggesting that the control condition – which took the same format in each study – did not reflect participants performing at floor level. This result would suggest that it should still have been possible to observe any potential between-group differences if the high trait anxiety groups in each study were to perform worse under certain conditions, as predicted.

Further research would help to confirm the relative roles of task demand and effortful processing, though, and the methods used in these present studies are easily modifiable to this aim. For example, the cued recall response method used in Studies 1 and 2 could be applied to the shorter memory arrays used in Study 3. Comparing cued recall with change detection at set sizes of three and four memory items could better disentangle whether effects of anxiety are, in the first instance, consistently observable in binding tasks, and also whether this is dependent on memory load and/or the effort required to complete the task. Direct comparisons between cued recall and change detection binding tasks have been limited. Comparing the response methods would help to better clarify the role of relatively automatic processing on performance (i.e., where verbal responses are not required) as compared with more elaborative processing (drawing upon previously learned verbal information to make a response to visual cues; see beginning of present Section 8.4).

8.5 Dimensions of anxiety and visual working memory

A key finding in the present research, regarding the results of Studies 3 and 4 in particular, was the different effects of the cognitive and somatic dimensions of trait anxiety on visual working memory performance. There was a more reliable association between trait somatic anxiety and performance than there was between trait cognitive anxiety and performance. Specific conclusions have been drawn in previous chapters regarding the finding across each of these studies, that trait somatic anxiety was associated with a feature binding deficit, both in comparison to individual feature memory (Study 3) and in moderate-high trait somatic anxiety scorers as compared with low scorers (Studies 3 and 4). However, it is worth considering at this stage the broader implications of these outcomes and the best means of further exploring these in order to better understand the means by which specific dimensions of anxious experiences may impact on cognitive functioning.

8.5.1 Trait somatic anxiety

Potentially the most important outcome from this aspect of the results is the implications for understanding how self-reported trait somatic anxiety may reflect cognitive vulnerabilities. The clear association between trait somatic anxiety and reduced colour-shape binding ability, also observed by Spalding et al. (2021), would suggest that the somatic subscale of the STICSA reflects a particular aspect of anxiety that is associated with cognitive functioning, more so than the cognitive subscale. Indeed, the somatic subscale has been shown to be less strongly correlated with measures of depression than the cognitive subscale (Roberts et al., 2016), suggesting that the somatic subscale better reflects anxious experiences. However, depression has also been shown to negatively impact working memory across the phonological loop, visuospatial sketchpad and central executive components (Christopher & MacDonald, 2005). This would suggest that it is not purely better divergence from depression that explains the observed effects of trait somatic anxiety as compared with cognitive anxiety. In determining what may differentiate the cognitive and somatic subscales with respect to depression, it is notable that anxiety and depression differ in the specific cognitions they invoke. Anxiety reflects worry, particularly about future events, and increased arousal – or emotionality – while depression reflects lack of positive affect and rumination on negative past events (Nolen-Hoeksema et al., 2008; Renner et al., 2018). If, then, the cognitive subscale of the STICSA is more closely associated with depression, it may less accurately reflect the extent of worry experienced in anxiety than does the somatic subscale. Certainly, the cognitive subscale does not reflect the heightened emotionality of anxiety as the somatic subscale does. It is therefore worth considering the potential cognitive implications of self-reporting higher levels of somatic anxiety.

As discussed in Sections 6.5.6 and 7.5.2, there is some evidence that suggests physical sensations do capture attention. Pain has been shown to demand attention and greater somatic self-awareness has been shown to reduce performance in attentionally demanding tasks (Eccleston & Crombez, 1998). Trait anxiety and anxiety disorders are also associated with greater monitoring of bodily signals (Ginzburg et al., 2014; Richards & Bertram, 2000; Zvolensky & Forsyth, 2002). It would follow that self-reported trait somatic anxiety reflects, to at least some degree, the extent of attention typically paid to bodily signals. As an example, there is evidence that anxiety sensitivity – i.e., one’s tendency to fear anxious sensations – is associated with the frequency, severity, and number of associated symptoms of headaches (Drahovzal et al., 2006). This particular example is useful in demonstrating that increased fear of anxious sensations is potentially reflective of greater reporting of anxious symptoms, highlighting a specific cognitive mechanism underlying trait somatic anxiety. Anxiety sensitivity can further be considered separate from trait anxiety – that is, the tendency to experience anxious sensations – and instead may be viewed as reflecting intolerance to distress (McHugh & Otto, 2011). Thus, while a causal link is yet to be established, there is a clear link between anxiety sensitivity and awareness of bodily sensations.

Based on the evidence described in the above paragraph, the somatic subscale of the STICSA could reflect increased anxiety sensitivity, in that participants who report more frequently experiencing somatic sensations are more closely monitoring these. As such, anxiety sensitivity could be the driving factor behind the effects of somatic anxiety observed in the present studies: a general propensity for monitoring bodily sensations that attracts attention from, or limits resources for, moment-to-moment cognitive functioning in a working memory task. This interpretation presents an excellent opportunity for future research to further examine the associations between trait somatic anxiety, anxiety sensitivity, and distress intolerance in predicting working memory capacity and cognitive performance. Thus far, studies have focused on how distress intolerance, anxiety sensitivity and working memory capacity predict behaviour, either separately or via interactions amongst them (e.g., Fitzgerald et al., 2021; Matsumoto & Kawaguchi, 2020), rather than causal relationships between anxiety sensitivity and working memory capacity. Indeed, Otto et al. (2016) assumed distress intolerance and working memory capacity to be associated with separate brain regions and therefore to interact in predicting performance but did not make assumptions regarding the possible causal associations between these. It would therefore be worthwhile determining whether there is any causal association between anxiety sensitivity, trait somatic anxiety and working memory ability. This would also be useful in determining whether the somatic subscale of the STICSA is in fact accurately measuring participants' general experience of somatic anxiety, or simply their subjective awareness of it (i.e., their increased interoception arising from anxiety sensitivity).

8.5.2 Trait cognitive anxiety

While the previous section provides suggestions as to why trait somatic anxiety was associated with a binding deficit in working memory, it is also necessary to address the positive association between trait cognitive anxiety and individual feature memory. In considering Studies 3 and 4 together, a notable limitation of Study 4 emerged retrospectively in light of the results from Study 3, which was conducted simultaneously with Study 4. In Study 3, it was found that performance effectiveness at moderate and high trait cognitive anxiety was significantly reduced for binding memory as compared to shape memory. But, further to this, a positive relationship was observed between trait cognitive anxiety and shape memory, with no effect of trait cognitive anxiety on binding memory only. Thus, not only was there a binding deficit associated with trait cognitive anxiety, but this also appeared to be driven specifically by improved performance for shape memory relative to other groups, rather than reduced binding memory compared to other groups. In retrospect, then, it was perhaps unlikely that effects of trait cognitive anxiety would emerge in Study 4, in which only binding memory was tested. That is, there was no scope in Study 4 to determine whether the positive association between trait cognitive anxiety and feature memory was reliable.

The positive impact of trait cognitive anxiety could be explained by effects of anxiety on motivation to perform well in cognitive tasks. If a particular assumption made regarding the results of Studies 1 and 2 in Section 8.4 is accurate – that task difficulty was responsible for the lack of significant effects of anxiety, and not motivation to perform well – then a combination of task difficulty and motivation to perform may explain the results of Study 3 with respect to trait cognitive anxiety. As discussed in Section 6.5.2, Moriya and Sugiura (2012) – in order to explain a positive effect of social anxiety on working memory performance – suggested that individuals who experience greater social anxiety may expend greater effort to process a greater amount of information in their environment. This greater effort is expended in order to better monitor other individuals' responses to social situations. To reiterate, social anxiety is thought to consist primarily of anxious cognitions (Hirsch & Mathews, 2012; Rapee, 1993; Rapee & Heimberg, 1997; Wells, 1995). Moriya and Sugiura's suggestion is consistent with Eysenck et al.'s (2007) proposal that individuals who experience greater levels of anxiety will show enhanced perceptual attention at the expense of executive attention. Applying this view to Study 3's paradigm, as individuals reported higher levels of trait cognitive anxiety, they would have been increasingly motivated to monitor their environment. Therefore, they would be better able to remember and recognise individual features, which require less focused executive attention to maintain than bindings.

In summarising this particular issue, much of the above explanations warrant a great deal of further research, given the limited focus in the literature on separating cognitive and somatic anxiety. At the most basic level, it remains to be seen whether the positive association between shape memory and trait cognitive anxiety is reliable, as this association has not been found in previous research comparing shape and binding memory in the context of anxiety (Spalding et al., 2021). Otherwise, it would be useful to assess the impact of an additional cognitive load on shape memory across trait cognitive anxiety levels, as shape memory may have been reduced under cognitive load (Allen et al., 2009; 2014; 2017; Hu et al., 2014; Hu et al., 2016; Karlsen et al., 2010. This possibility presents a useful direction for a future study to consider whether cognitive load not only further diminishes memory with higher anxiety, which was not the case here, but also reduces benefits under lower perceptual memory loads. It would help to draw further parallels with the suggested role of attention in visual working memory emerging from the binding literature. That is, it would be possible to confirm whether executive attention is involved in remembering shapes at higher levels of trait cognitive anxiety or, as suggested, feature memory benefits specifically from increased perceptual attention in this context.

With further regard to the potential role of effortful processing on visual working memory performance (see Section 8.4), it would be useful to account for the consistent use of concurrent tasks across studies. In Studies 1-3, participants were asked to perform a concurrent number repetition task during encoding and maintenance of the memory arrays. In Study 4, participants' performance while performing the concurrent number repetition task was compared with their performance while performance a concurrent backwards counting task. Thus, there were no conditions across the studies which assessed performance at different levels of anxiety when there were no restrictions on encoding strategy. Regarding trait cognitive anxiety, it has previously been argued that the primary cognitive component of anxiety, that is, worry, typically manifests in negative self-statements that are subvocalised (e.g. Hirsch & Mathews, 2012; Rapee, 1993; Rapee & Heimberg, 1997; Wells, 1995). It is therefore possible that any negative effects of trait cognitive anxiety were masked in the present studies due to the suppression of these distracting, task-unrelated, anxious cognitions. Although articulatory suppression has been shown to further disrupt anxious individuals' performance in the verbal domain (Calvo, 1996), this effect may not apply to the visual domain, particularly if using probe recognition or change detection responses (see Section 8.4). Furthermore, previous studies that have found effects of anxiety on behavioural working memory outcomes appear not to have employed any articulatory suppression methods (Berggren, 2020; Jaiswal et al., 2018). The potential suppression of anxious cognitions by number repetition would in fact provide one explanation for the positive association between trait cognitive anxiety and shape memory in Study 3. If the negative cognitions associated with anxiety are suppressed by repeated articulation of a two-digit number, but the individual is still generally anxious from day-to-day, they may not be distracted by task-unrelated thoughts, but still process stimuli more effectively at the perceptual level, due to increased arousal or inherently higher motivation to monitor their environment. There is some evidence in support of the view that distracting thoughts can be minimised by concurrent tasks or memory load. High working memory load, at least, has been associated with reduced anxiety (King & Shaefer, 2011; Vytal et al., 2013). Beyond the study of anxiety, evidence from studies of more general task-unrelated or task-interfering thoughts presents a compelling case to assess the possibility that dual tasking may minimise the effects of anxious cognitions on performance. Task unrelated thoughts have been shown to be reduced to a greater extent when encoding meaningful content (words compared to non-words; Smallwood et al., 2004). If concurrent tasks can mitigate the impact of anxiety on cognitive abilities, this finding would present an important means of advancing the understanding of the cognitive impacts of anxiety initially outlined in ACT (Eysenck et al., 2007), which only focuses on attentional shifting, inhibition and updating. Specifically, it could extend ACT to consider the ability to coordinate multiple tasks (see Wong et al., 2013) and also to clarify whether there is a benefit to increasing thoughts unrelated to a given task or situation for reducing the negative cognitive and somatic impacts of anxiety.

Considering further the effects of thoughts that may interfere with - rather than distract from - task performance, studies employing situational stress paradigms (e.g., Edwards et al., 2017; Spalding et al., 2021) may further help to disentangle the specific types of thoughts that influence performance in anxiety. There is a difference between thoughts that interfere with a task – such as worry about task performance – and thoughts that distract attention away from a task, these being thoughts entirely unrelated to the present task (e.g., Smallwood et al., 2003). Spalding et al. (2021) provided evidence that situational stress (induced by informing participants they were performing below average on a test of intelligence), trait cognitive anxiety, and trait somatic anxiety all separately predicted reduced performance in a visual binding task. This would suggest that the specific thoughts invoked during the task (task-related stress, general anxious cognitions, and general somatic anxiety) each have separable effects on cognitive performance. However, with regards to attention, Edwards et al. (2017) have shown that the interaction between trait anxiety and situational stress predicts performance. It would be useful to consider, as far as possible, the real-time fluctuations in state anxiety that occur during cognitive tasks in order to determine whether these are predicted by self-reported trait anxiety and whether these fluctuations, in turn, predict performance. Further to measures of task-related stressors, anxiety induction measures such as threat of shock (see Robinson et al., 2013) may help to indicate how ongoing task irrelevant stressors interact with trait anxiety to predict performance, or indeed separately predict performance. It would therefore be possible to assess the different effects of task-relevant worries and task-irrelevant worries. Employing physiological and neurological markers of anxiety alongside self-report measures would be one means of measuring anxiety in this context (e.g., Choi et al., 2012; Derakshan & Eysenck. 2001; Heeren et al., 2012). Subjective self-reported state anxiety may also be measured during tasks or at various time points over the course of an experimental session (e.g., Edwards et al., 2006; 2010; Spalding et al., 2021). It would also be worthwhile exploring the effects of mindfulness in the context of anxious experiences distracting from task performance. Mindfulness is the ability to regulate and focus attention on a present situation and reduce cognitive and emotional distress in the process (Bishop et al., 2004). While Jaiswal et al. (2018) have presented evidence suggesting working memory performance is impaired in a high anxiety-low mindfulness group compared to a low-anxiety-high mindfulness group, they have not compared these groups with high anxiety-high mindfulness groups or low anxiety-low mindfulness groups. These further comparisons are necessary in order to determine whether it is anxiety or mindfulness specifically, or an interaction between the two, that affect performance. Considering the relative benefits of mindfulness and working memory load in reducing anxiety would help to further clarify how cognitive performance decrements associated with anxiety may be alleviated.

8.6 Further implications for visual working memory and attention

Regarding implications for the understanding of working memory more generally, some conclusions can be drawn from overall task performance in each study sample. In summary, the observed main effects largely followed findings within the previous binding literature. Performance was reduced by suffix presentation (e.g., Ueno, Allen, et al., 2011; Ueno, Mate et al., 2011; Hu et al., 2014, 2016) and cognitive load (e.g., Allen et al., 2009, 2017; Hu et al., 2016; Karlsen et al., 2010), while serial binding memory was worse than shape memory (Allen et al., 2006; Brown & Brockmole, 2010; Brown et al., 2017). One remaining point worth resolving however is that the results were less consistent when considering specific patterns observed in the form of interactions or from serial position analyses. Although serial position curves were observed, there were instances where these were not as pronounced as may be expected. In Study 4, for example, performance was consistently lower at position two than at other serial positions, as expected, but there was no clear advantage for position four compared with positions one and three. This was at odds with the other present studies, where performance at serial position four was consistently better than at the other positions, as would be expected. This result could again be explained in the context of task difficulty. In Studies 1 and 2, performance at the early serial positions likely suffered to a greater degree as it was more difficult to recall these items (see Section 8.4). By comparison, in Study 3, both shape and binding memory at position four would have been easier to recall than the earlier positions due to the automatic nature by which items at this position are processed (Hitch et al., 2020). The lack of pronounced advantage for serial position in Study 4, then, could have been the result of cognitive load attenuating the performance advantage for this position.

Similarly to cognitive load, suffix presentation did not interact with serial position in Study 2, but suffix presentation did reduce performance, suggesting that the presentation of a visual suffix served to increase the overall task load for participants. However, the lack of advantage for the final serial position in Study 4 is at odds with previous studies which have shown that cognitive load disproportionately affects the prior positions in a sequence (Allen et al., 2014; Hu et al. 2014). Specific suggestions regarding the lack of interactive effects are provided in the respective chapters for each study, but here it is useful to highlight that task-specific factors such as presentation format may account for these differences in results. Also, while each study was powered sufficiently to detect the predicted three-way interactions (and in the case of Studies 3 and 4 to detect a main effect of anxiety), significant repeated-measures interactions may have failed to emerge when comparing performance across groups.

One useful contribution of the present research to the understanding of visual working memory more generally is the evidence that single probe recognition tasks were more sensitive to individual differences than were cued recall tasks. As discussed in Section 8.4 of this chapter, a likely explanation for this is the level of processing required for each type of response. By this approach, recognition memory may better reflect attentional processes specific to the visual domain than memory processes across domains. It would appear that studies of binding have yet to directly compare different methods of response in the context of the present manipulations (i.e. cognitive load, serial position, memory type, and suffix interference). Direct comparison of the magnitude of effect of each manipulation presents a means of clarifying the sensitivity of these response methods in future.

The present research is a useful step forward for developing a better understanding of the role of emotion within working memory, particular multicomponent models. Baddeley et al. (2012; see also Baddeley, 2013) argued that effects of anxiety fit relatively easily within a multicomponent working memory framework if it is accepted that there exists an attentional filter, which is less protective of the influence of threatening stimuli as anxiety increases. Indeed, the present hypotheses were informed by the prospect that individuals who are more anxious would fail to successfully filter information from memory more so than those who are less anxious, and fail to maintain earlier encountered stimuli via executive attention (see Eysenck et al., 2007; Derakshan & Eysenck, 2011; Berggren & Derakshan, 2013). However, as noted in Section 8.3.1, the present results do not provide clear support for the influence of anxiety on attention at either the executive or perceptual level. The observed effects of anxiety on working memory were more general, suggesting that anxiety may in fact impact on working memory through other components of the visual working memory model (see Figure 8.1).

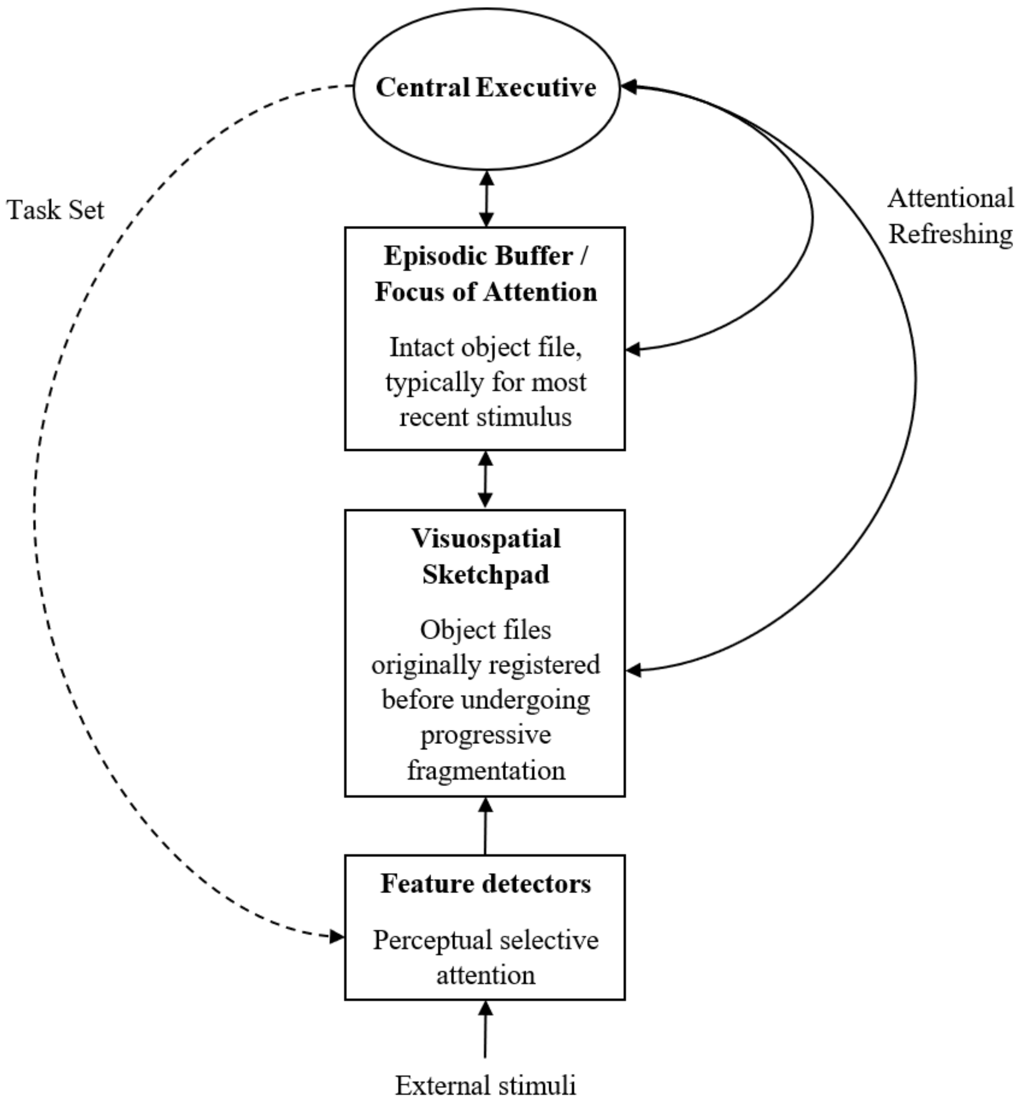

Figure 8.1 The main components of visual working memory and their associated functions outlined by (and adapted from) Hitch et al. (2020).

As suggested in Section 6.5.3, it would be useful to frame future research and theoretical discussion of the effects of emotion on visual working memory from the perspective of the episodic buffer. With the episodic buffer being responsible for the integration of information from multiple domains, as well as the focus of attention (Hitch et al., 2020), this mechanism may help to explain the present results. A lack of clear interaction between anxiety and serial position suggests that it is not simply top-down or bottom-up processing that is affected by anxiety. Instead, anxiety deficits appear to be specific to feature binding in trait somatic anxiety, and feature binding relative to shape memory in trait cognitive anxiety. Referring again to Section 6.5.3, anxiety may distract attention away from information that has already been encountered, meaning that the focus of attention is not appropriately directed to task-relevant information.

8.7 Conclusions

Although the research reported in this thesis was less informative for better understanding the specific attentional mechanisms through which anxiety may negatively impact on working memory, there were several novel, informative outcomes. An association between trait anxiety and visual working memory - an increasingly common finding in recent literature - was supported. The key contribution to knowledge in this area was the different effects of self-reported cognitive and somatic anxiety, measured at the trait level, on performance. Most strikingly, trait somatic anxiety was a more reliable predictor of reduced visual working memory performance. There was limited theoretical basis for this outcome, although recent studies examining trait somatic anxiety and interoception provided a means of interpreting these results. Another valuable outcome in this regard was providing further evidence that trait somatic anxiety can negatively impact behavioural effectiveness as opposed to only neural activity or behavioural efficiency. The discussions throughout this chapter outline the means by which future research can develop a better understanding of the impact of anxiety on capturing attention and influencing behavioural cognitive performance. It would be beneficial for future research to consider the potential that cognitive and somatic anxiety differentially impact on cognitive performance. This research also suggests that performance differences associated with anxiety may only emerge under conditions in which less effortful cognitive processing is required. Alternatively, the results could suggest differences will only emerge under task conditions that are not overly demanding as to severely reduce performance in an overall sample of varying anxiety levels. Again, further determining the specific mechanism – cognitive effort or task demand – behind the range of findings observed here will have further implications for an as yet underdeveloped assumption within Attentional Control Theory, namely the interaction between anxiety and motivation (Eysenck et al., 2007; see also Berggren & Derakshan, 2013). Determining the influence of these mechanisms on working memory performance would also help to advance general working memory models by being more comprehensive in accounting for the role of emotion on cognitive processing.

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Appendix A The State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree et al., 2008)

Ref ________________ Date _____________

STICSA
General Mood Questionnaire

Below is a list of statements which can be used to describe how people feel. Beside each statement are four numbers which indicate *how often* each statement is true of you (eg, 1 = almost never, 4 = almost always**).** *Please read each statement carefully and circle the number which best indicates* **how often*, in general, the statement is true of you.***

In general.....	Almost never	Occasionally	Often	Almost always
1. My heart beats fast	1	2	3	4
2. My muscles are tense	1	2	3	4
3. I feel agonised over my problems	1	2	3	4
4. I think that others won't approve of me.	1	2	3	4
5. I feel like I'm missing out on things because I can't make up my mind soon enough	1	2	3	4
6. I feel dizzy.	1	2	3	4
7. My muscles feel weak	1	2	3	4
8. I feel trembly and shaky	1	2	3	4
9. I picture some future misfortune.	1	2	3	4
10. I can't get some thought out of my mind.	1	2	3	4
11. I have trouble remembering things	1	2	3	4
12. My face feels hot	1	2	3	4
13. I think that the worst will happen.	1	2	3	4
14. My arms and legs feel stiff	1	2	3	4
15. My throat feels dry	1	2	3	4
16. I keep busy to avoid uncomfortable thoughts	1	2	3	4
17. I cannot concentrate without irrelevant thoughts intruding	1	2	3	4
18. My breathing is fast and shallow	1	2	3	4
19. I worry that I cannot control my thoughts as well as I would like to.	1	2	3	4
20. I have butterflies in the stomach.	1	2	3	4
21. My palms feel clammy	1	2	3	4

Ref ______________ Date ____________

STICSA
Your Mood at This Moment

Below is a list of statements which can be used to describe how people feel. Beside each statement are four numbers which indicate the degree with which each statement is self-descriptive of your mood at this moment (eg, 1 = not at all, 4 = very much so). *Please read each statement carefully and circle the number which best indicates* **how you feel right now, at this very moment*, even if this is not how you usually feel*.**	Not at all	A little	Moderately	Very much so
In general.....				
1. My heart beats fast	1	2	3	4
2. My muscles are tense	1	2	3	4
3. I feel agonised over my problems	1	2	3	4
4. I think that others won't approve of me.	1	2	3	4
5. I feel like I'm missing out on things because I can't make up my mind soon enough	1	2	3	4
6. I feel dizzy.	1	2	3	4
7. My muscles feel weak	1	2	3	4
8. I feel trembly and shaky	1	2	3	4
9. I picture some future misfortune.	1	2	3	4
10. I can't get some thought out of my mind.	1	2	3	4
11. I have trouble remembering things	1	2	3	4
12. My face feels hot	1	2	3	4
13. I think that the worst will happen.	1	2	3	4
14. My arms and legs feel stiff	1	2	3	4
15. My throat feels dry	1	2	3	4
16. I keep busy to avoid uncomfortable thoughts	1	2	3	4
17. I cannot concentrate without irrelevant thoughts intruding	1	2	3	4
18. My breathing is fast and shallow	1	2	3	4
19. I worry that I cannot control my thoughts as well as I would like to.	1	2	3	4
20. I have butterflies in the stomach.	1	2	3	4
21. My palms feel clammy	1	2	3	4

Appendix B The Depression Anxiety Stress Scales, 21-item version (DASS-21; Lovibond & Lovibond, 1995)

DASS21

Name: Date:

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

1	I found it hard to wind down	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I found it difficult to work up the initiative to do things	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I experienced trembling (eg, in the hands)	0	1	2	3
8	I felt that I was using a lot of nervous energy	0	1	2	3
9	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting agitated	0	1	2	3
12	I found it difficult to relax	0	1	2	3
13	I felt down-hearted and blue	0	1	2	3
14	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
15	I felt I was close to panic	0	1	2	3
16	I was unable to become enthusiastic about anything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I was aware of the action of my heart in the absence of physical exertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life was meaningless	0	1	2	3

Appendix C Prioritisation instructions in Study 1

Control block

You will be shown sequences of 4 coloured shapes and asked to remember them. In the following trials, correct recall will be worth 1 point.

'Prioritise item 1' block

You will be shown sequences of 4 coloured shapes and asked to remember them. In the following trials, correct recall of the FIRST item in the sequence will be worth 4 points. Correct recall of the second, third and fourth items will be worth 1 point. Although you will be awarded more points for correctly recalling the first item, keep in mind that this will not always be the item you need to remember, i.e. any item in the sequence may be tested.

'Prioritise item 4' block

You will be shown sequences of 4 coloured shapes and asked to remember them. In the following trials, correct recall of the FOURTH item in the sequence will be worth 4 points. Correct recall of the first, second, and third items will be worth 1 point. Although you will be awarded more points for correctly recalling the fourth item, keep in mind that this will not always be the item you need to remember, i.e. any item in the sequence may be tested.

Appendix D Correlations between STICSA subscales, DASS subscales, and performance effectiveness in Study 1

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Trait cognitive anxiety (STICSA)	-								
2. Trait somatic anxiety (STICSA)	.52***	-							
3. State cognitive anxiety (STICSA)	.73***	.37**	-						
4. State somatic anxiety (STICSA)	.46***	.56***	.57***	-					
5. Depression (DASS)	.75***	.43***	.67***	.47***	-				
6. Anxiety (DASS)	.59***	.72***	.57***	.62***	.66***	-			
7. Stress (DASS)	.65***	.47***	.56***	.47***	.66***	.71***	-		
8. Binding accuracy (control)	-.08	.04	.-.03	.16	-.04	.03	.07	-	
9. Binding accuracy (item 1 worth more)	-.12	.08	-.15	-.01	-.22	-.09	.04	.53***	-
10. Binding accuracy (item 4 worth more)	-.33**	-.20	-.27*	-.09	-.27*	-.20	-.01	.46***	.56***

*** $p < .001$, ** $p < .01$, * $p < .05$

Appendix E Full fixed-effects results of the multilevel model analyses for proportion correct responses in Study 1

	Numerator df	**Denominator df**	***F***	**Sig.**
Trait cognitive anxiety	1	67.00	3.32	.073
Instruction	2	67	0.304	.739
Serial position	3	67	83.90	.000
Trait cognitive anxiety x prioritisation instruction	2	67	2.60	.082
Trait cognitive anxiety x serial position	3	67	0.90	.447
Instruction x serial position	6	67	1.43	.218
Trait cognitive anxiety x instruction x serial position	6	67	0.29	.942

Appendix F Suffix instructions in Study 2

Control (no suffix) block

In this set of trials you will be shown sequences of 4 coloured shapes - please try to remember these. Following the presentation of these items, you will see either a blob of colour or a blank shape. If you see a blob of colour, please try to recall out-loud the shape that the colour was originally presented with. If you see a blank shape, please try to recall out-loud the colour that the shape was originally presented with.

Plausible and implausible suffix blocks

In this set of trials you will be shown sequences of 4 coloured shapes - please try to remember these. After these first 4 items are presented you will see another coloured shape, which you should try to ignore, as your memory for this will not be tested. Following the presentation of these items, you will see either a blob of colour or a blank shape. If you see a blob of colour, please try to recall out-loud the shape that the colour was originally presented with. If you see a blank shape, please try to recall out-loud the colour that the shape was originally presented with.

Appendix G Correlations between STICSA subscales, DASS subscales, and performance effectiveness in Study 2

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1. Trait cognitive anxiety (STICSA)	-											
2. Trait somatic anxiety (STICSA)	.58***	-										
3. State cognitive anxiety (STICSA)	.56***	.25*	-									
4. State somatic anxiety (STICSA)	.32**	.43***	.58***	-								
5. Depression (DASS)	.63***	.46***	.41***	.28*	-							
6. Anxiety (DASS)	.55***	.64***	.39**	.54***	.49***	-						
7. Stress (DASS)	.70***	.56***	.47***	.36**	.60***	.56***	-					
8. Binding accuracy (shape cues, control)	-.10	.17	-.31	-.15	-.09	-.05	-.08	-				
9. Binding accuracy (shape cues, plausible suffix)	.03	.14	-.05	-.05	-.05	-.09	.17	.07	-			
10. Binding accuracy (shape cues, implausible suffix)	.12	.12	-.01	-.06	.03	.11	.15	.10	.29*	-		
11. Binding accuracy (colour cues, control)	.02	-.03	.09	-.06	.09	.01	.03	.18	.04	.21	-	
12. Binding accuracy (colour cues, plausible suffix)	.12	.15	.12	-.09	.15	.11	.16	.09	.27*	.24*	.25*	
13. Binding accuracy (colour cues, implausible suffix)	-.08	-.03	-.01	-.05	.08	-.10	-.02	-.07	.12	.38**	.16	.16

*** $p < .001$, ** $p < .01$, * $p < .05$

Appendix H Full fixed-effects results of the multilevel model analyses for proportion correct responses in Study 2

	Numerator df	Denominator df	*F*	Sig.
Trait cognitive anxiety	1	68.00	0.12	.735
Suffix	2	68.00	22.54	.000
Serial position	3	68.00	67.14	.000
Trait cognitive anxiety x suffix	2	68.00	0.46	.632
Trait cognitive anxiety x serial position	3	68.00	2.74	.050
Suffix x serial position	6	68	1.28	.276
Trait cognitive anxiety x suffix x serial position	6	68	0.23	.965

Appendix I Memory type and set size instructions in Study 3

Shape memory

In this block you will be shown sequences of [3/4] coloured shapes, and asked to remember these. At the start of each trial you will be shown a 2-digit number. Please begin repeating this number out loud when you see it, and keep doing so until you have made your response. At the end of each trial you will be shown one blank shape, and you should indicate whether you think this particular shape appeared in the earlier array. Press the 'Yes' key if you think it appeared, and the 'No' key if not.

Binding memory

In this block you will be shown sequences of [3/4] coloured shapes, and asked to remember these. At the start of each trial you will be shown a 2-digit number. Please begin repeating this number out loud when you see it, and keep doing so until you have made your response. At the end of each trial you will be shown one coloured shape, and you should indicate whether this particular colour-shape combination appeared in the earlier array. Pres the 'Yes' key if you think it appeared, and the 'No' key if not. The shape must have originally appeared in the particular colour shown for a 'Yes' response to be correc

Appendix J Correlations between STICSA subscales, DASS subscales, performance effectiveness and performance efficiency outcomes in Study 3

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Trait cognitive anxiety (STICSA)	-									
2. Trait somatic anxiety (STICSA)	.65***	-								
3. State cognitive anxiety (STICSA)	.70***	.57***	-							
4. State somatic anxiety (STICSA)	.31**	.72***	.43***	-						
5. Depression (DASS)	.59***	.46***	.71***	.40***	-					
6. Anxiety (DASS)	.46***	.64***	.64***	.65***	.73***	-				
7. Stress (DASS)	.47***	.43***	.60***	.41***	.75***	.73***	-			
8. Shape accuracy	.39***	.10	.18	-.15	.08	-.08	.00	-		
9. Binding accuracy	-.12	-.28**	-.13	-.12	-.07	-.13	-.03	.44***	-	
10. Shape efficiency	.08	.14	.18	.32*	.21*	.25**	.20	-.22*	.06	-
11. Binding efficiency	-.12	-.01	.05	.30*	.12	.20	.12	-.33*	.25*	.82***

*** $p < .001$, ** $p < .01$, * $p < .05$

Appendix K Full fixed-effects results of the multilevel model analyses for effectiveness and efficiency outcomes in Study 3

Trait cognitive anxiety, effectiveness

	Numerator df	**Denominator df**	***F***	**Sig.**
Trait cognitive anxiety	1	84.00	2.97	.089
Set size	1	84.00	82.94	.000
Memory type	1	84.00	135.64	.000
Trait cognitive anxiety x set size	1	84.00	0.13	.719
Trait cognitive anxiety x memory type	1	84.00	29.77	.000
Set size x memory type	1	84.00	6.13	.015
Trait cognitive anxiety x set size x memory type	1	84.00	0.38	.539

Trait somatic anxiety, effectiveness

	Numerator df	Denominator df	***F***	Sig.
Trait somatic anxiety	1	84.00	0.64	.425
Set size	1	84.00	83.29	.000
Memory type	1	84.00	102.10	.000
Trait somatic anxiety x set size	1	84.00	0.16	.686
Trait somatic anxiety x memory type	1	84.00	10.71	.002
Set size x memory type	1	84.00	6.11	.015
Trait somatic anxiety x set size x memory type	1	84.00	2.69	.105

Trait cognitive anxiety, efficiency

	Numerator df	Denominator df	*F*	Sig.
Trait cognitive anxiety	1	84.00	0.06	.812
Set size	1	84	22.40	.000
Memory type	1	84.00	36.15	.000
Trait cognitive anxiety x set size	1	84	0.23	.633
Trait cognitive anxiety x memory type	1	84.00	10.01	.002
Set size x memory type	1	84	3.16	.079
Trait cognitive anxiety x set size x memory type	1	84	0.01	.905

Trait somatic anxiety, efficiency

	Numerator df	Denominator df	*F*	Sig.
Trait somatic anxiety	1	84	0.33	.567
Set size	1	84	22.57	.000
Memory type	1	84	34.86	.000
Trait somatic anxiety x set size	1	84	0.001	.970
Trait somatic anxiety x memory type	1	84	4.99	.028
Set size x memory type	1	84	3.40	.069
Trait somatic anxiety x set size x memory type	1	84	3.24	.075

Appendix L Cognitive load and set size instructions in Study 4

Control (articulatory suppression) block

In this block you will be shown sequences of [3/4] coloured shapes, and asked to remember these. At the start of each trial you will be shown a 2-digit number. Please begin repeating this number out loud when you see it, and keep doing so until you have made your response. At the end of each trial you will be shown one coloured shape, and you should indicate whether this particular colour-shape combination appeared in the earlier array. Pres the ‘Yes’ key if you think it appeared, and the ‘No’ key if not. The shape must have originally appeared in the particular colour shown for a ‘Yes’ response to be correct.

Load (backwards counting) block

In this block you will be shown sequences of [3/4] coloured shapes, and asked to remember these. At the start of each trial you will be shown a 2-digit number. Please begin counting backwards from this number out loud – in threes – when you see it, and keep doing so until you have made your response. At the end of each trial you will be shown one coloured shape, and you should indicate whether this particular colour-shape combination appeared in the earlier array. Pres the ‘Yes’ key if you think it appeared, and the ‘No’ key if not. The shape must have originally appeared in the particular colour shown for a ‘Yes’ response to be correct.

Appendix M Correlations between STICSA subscales, DASS subscales, performance effectiveness and performance efficiency outcomes in Study 4

	1	2	3	4	5	6	7	8	9	10
1. Trait cognitive anxiety (STICSA)	-									
2. Trait somatic anxiety (STICSA)	.66**	-								
3. State cognitive anxiety (STICSA)	.69**	.53**	-							
4. State somatic anxiety (STICSA)	.43**	.67**	.58**	-						
5. Depression (DASS)	.72**	.61**	.74**	.51**	-					
6. Anxiety (DASS)	.72**	.78**	.58**	.52**	.76**	-				
7. Stress (DASS)	.75**	.64**	.75**	.55**	.81**	.75**	-			
8. Control binding accuracy	-.15	-.11	-.04	-.10	-.07	-.11	-.01	-		
9. Load binding accuracy	.01	-.10	-.03	-.13	-.03	-.02	.00	.37*	-	
10. Control binding efficiency	-.03	-.03	-.12	-.15	-.19	-.11	-.16	.01	-.03	-
11. Load binding efficiency	.02	-.07	-.08	-.20	-.12	-.08	-.10	.01	.43**	.68**

** $p < .001$, * $p < .01$

Appendix N Full fixed-effects results of the multilevel model analyses for effectiveness and efficiency outcomes in Study 4

Trait cognitive anxiety, effectiveness

	Numerator df	**Denominator df**	***F***	**Sig.**
Trait cognitive anxiety	1	66.00	.47	.495
Set size	1	66	23.48	.000
Load	1	66.00	64.24	.000
Trait cognitive anxiety x set size	1	66	0.31	.580
Trait cognitive anxiety x load	1	66.00	1.48	.229
Set size x load	1	66.00	0.96	.332
Trait cognitive anxiety x set size x load	1	66.00	2.46	.122

Trait somatic anxiety, effectiveness

	Numerator df	Denominator df	*F*	Sig.
Trait somatic anxiety	1	66.00	1.15	.288
Set size	1	66.00	23.40	.000
Memory type	1	66	62.84	.000
Trait somatic anxiety x set size	1	66.00	0.10	.749
Trait somatic anxiety x load	1	66.00	0.01	.936
Set size x load	1	66.00	0.94	.337
Trait somatic anxiety x set size x load	1	66.00	1.01	.318

Trait cognitive anxiety, efficiency

	Numerator df	Denominator df	*F*	Sig.
Trait cognitive anxiety	1	66	1.00	.960
Set size	1	66.00	20.32	.000
Load	1	66.00	195.60	.000
Trait cognitive anxiety x set size	1	66.00	0.59	.447
Trait cognitive anxiety x load	1	66.00	0.28	.598
Set size x load	1	66	0.13	.718
Trait cognitive anxiety x set size x load	1	66	1.01	.318

Trait somatic anxiety, efficiency

	Numerator df	Denominator df	*F*	Sig.
Trait somatic anxiety	1	66	0.18	.674
Set size	1	66.00	20.14	.000
Load	1	66.00	195.08	.000
Trait somatic anxiety x set size	1	66.00	0.00	.985
Trait somatic anxiety x load	1	66.00	0.10	.749
Set size x load	1	66.00	0.13	.718
Trait somatic anxiety x set size x load	1	66.00	1.07	.305