Towards understanding the impacts of anxiety on attention and visual working memory.

David M. Spalding and Louise A. Brown Nicholls

School of Psychological Sciences & Health, University of Strathclyde, Glasgow, UK.

Email: david.m.spalding@strath.ac.uk; Twitter: @DSpaldingStrath

Email: l.nicholls@strath.ac.uk; Twitter: @LNichollsStrath

Lab webpage: https://www.researchgate.net/lab/Memory-Ageing-Lab-Louise-A-Brown-Nicholls

ANXIETY, ATTENTION, VISUAL WORKING MEMORY, VISUAL FEATURE BINDING

Anxiety can refer to a dispositional trait characteristic, a transient emotional state, or a classification of mood disorders that can be broadly defined by a range of key aspects. Individuals with more anxious dispositions will more frequently experience apprehension and worry, leading to more frequent experiences of anxious states, particularly under stressful conditions (e.g. Eysenck et al., 2007). Anxious states can be characterized by these apprehensions, as well as the experience of somatic hyperarousal and tension (e.g. Moran, 2016; Ree et al., 2008). The estimated 12-month prevalence of anxiety disorders in the UK was

18.1% of the population in 2010 (Fineberg et al., 2013). Though, in Europe and North America, estimates of those who experience chronic anxiety below the threshold for a clinical diagnosis has been suggested to be twice that of diagnosed cases (Haller et al., 2014). Even within nonclinical groups, anxiety is associated with reduced personal, social and professional functioning (Haller et al., 2014). Additionally, there is a longstanding body of evidence suggesting that anxiety is related to impaired attentional control (e.g. Eysenck et al., 2007, Berggren & Derakshan, 2013), which may limit working memory capacity (Moran, 2016). Despite this, studies of the impact of anxiety on working memory, particularly in the visual domain, remain relatively few in number. The purpose of this review is to highlight our developing understanding of the impacts of anxiety on cognition, and the future directions that research in this area may usefully take.

Attentional Control Theory

In recent years, Attentional Control Theory (ACT; Eysenck et al., 2007) has helped define the effects of anxiety on cognitive functioning. ACT integrates various assumptions from the attention and working memory literature. First, it is suggested that anxiety impacts the central executive via reduced control of the lower-level executive functions identified by Miyake et al. (2000; see also Friedman & Miyake, 2017): the inhibition of prepotent responses and irrelevant stimuli; shifting between tasks and mental sets; and updating the contents of working memory. In particular, effects have been consistently observed across attentional shifting and inhibition. Difficulties in attentional inhibition have been observed with higher levels of anxiety across a range of tasks. For example, slower saccades away from non-target to target stimuli suggest an

inability for highly anxious individuals to inhibit attention to distractors (e.g. Derakshan, Ansari et al., 2009). Likewise, slower visual search performance in the presence of distractors and larger search arrays has also been observed (Moser et al. 2012; Sadeh & Bredemeier, 2011). With regard to shifting attention, highly anxious individuals have demonstrated increased difficulty switching to new task sets in the Wisconsin Card Sorting Test (e.g. Edwards et al., 2015) or switching between different tasks (Derakshan, Smyth et al., 2009).

ACT also includes the assumption that perceptual and executive attention are separable (e.g. Corbetta & Schulman, 2002). Specifically, it is suggested that, while executive control is reduced, perceptual receptivity is increased. Anxious individuals are better able to identify the presentation of additional stimuli during a visual search task (Berggren et al., 2015), suggesting not only that anxious individuals are more likely to be distracted by other visual objects, but also better able to detect them. Meanwhile, studies adopting the Attentional Network Test (ANT; Fan et al., 2002) and ANT-Interactions (Callejas et al., 2004), have shown an association between increased functioning of the alerting and orienting networks at higher levels of trait anxiety. Orienting has been positively associated with anxiety specifically when the period between presentation of the orienting cue and target cue is short enough to facilitate the automatic orienting of attention (e.g. Pacheco-Unguetti et al., 2010). However, a negative association between orienting and anxiety has been observed when the interval is so long that attention might have to be voluntarily directed towards the target (e.g. Heeren et al., 2015). Thus, anxiety appears to facilitate bottom-up attentional capture, with control over the direction of attention itself impeded.

It is important to note that across the studies mentioned above, the effects of anxiety typically impact on the speed, rather than the accuracy, with which anxious participants perform cognitive tasks. This highlights the other major assumption within ACT: anxiety affects processing efficiency more so than effectiveness. This assumption is important with respect to the current understanding of anxiety on cognition, as inherent within this is the notion that highly anxious individuals can potentially expend additional effort to maintain a similar level of task performance effectiveness as less anxious individuals. In tasks where less effortful processing is required, for example under conditions of low perceptual load, highly anxious individuals have demonstrated reduced dorsolateral prefrontal cortex (DLPFC; Bishop, 2009) and frontocentral event-related potential (ERP) activity (Ansari & Derakshan, 2011) alongside lower behavioural efficiency. Interestingly, however, in tasks requiring more effortful processing, e.g. resolving incongruency in a Stroop task (Basten et al., 2011), or maintaining representations in a three-back task (Fales et al., 2008), highly anxious individuals have shown an increase in DLPFC activity, possibly indicating greater effort to exercise executive control.

ACT and related evidence therefore allow us to make clear predictions as to the effects of anxiety on attention. Namely, higher anxiety increases bottom-up attention at the expense of executive control, and resulting in reduced performance efficiency, and sometimes effectiveness, depending on the conditions of a given cognitive task. However, the assumptions are less clear regarding the effects of anxiety on working memory. Typically, it has been assumed that anxiety impacts cognition through worry. Worry is thought to primarily manifest as subvocal speech, therefore engaging the phonological loop (e.g. Elliman et al., 1997; Rapee 1993). It draws on limited attentional resources, impacting executive processing capacity

(Eysenck & Calvo, 1992; Eysenck et al., 2007). Indeed, a recent meta-analysis indicates consistent effects of anxiety on verbal and spatial working memory, but not for purely visual working memory (Moran, 2016). However, this could owe to the relatively little research conducted on anxiety and visual working memory that involves tasks with little or no spatial elements. Nonetheless, much of the evidence for an effect of anxiety on attention comes from visuospatial tasks (e.g. visual search, antisaccade tasks and the ANT). Therefore, there is an exciting opportunity for future research to help develop understanding of the impacts of anxiety on attention and working memory by employing visual working memory paradigms. Simultaneously, this should also progress understanding of the role of attention in visual working memory more generally.

Visual feature binding

In recent proposals of the structure of visual working memory it is suggested that executive and perceptual attention are separable but associated functions in working memory (e.g. Hitch et al., 2020; Hu et al., 2014). Perceptual attention is responsible for filtering external stimuli, leading to the formation of object files that occupy visuospatial storage (i.e. the visuospatial sketchpad). Object files can enter an active, limited capacity focus of attention, containing as little as a single item or chunk (e.g. Hitch et al., 2018), but they are subject to interference from subsequently encountered stimuli. Executive attentional resources can serve to help maintain object representations in the face of interference, and, if required, reactivate stored representations in working memory.

Evidence from studies on visual feature binding over the past 20 years or so has helped to inform this view. Binding is the process by which individual features are processed and represented as complete, integrated objects. Allen et al. (2006) presented evidence for a pronounced recency effect in memory for sequences of (bound) coloured shapes vs the individual features (i.e. the colours or shape themselves; see also Brown et al., 2017). This indicated that bindings are relatively fragile to being overwritten by subsequently presented stimuli. Furthermore, a concurrent cognitive load served to further impair memory for earlier presented objects, with limited interference on the most recently presented object (Allen et al., 2014). Thus, bindings presented earlier in a sequence appear to rely on executive resources in order to be maintained in the face of interference and fragmentation over time, with the most recently encountered object entering the focus of attention relatively automatically.

The particular benefit of applying the visual featuring binding paradigm to the study of the impact of anxiety on cognition becomes even more apparent when considering results from studies which assessed the effects of distraction. In these studies, an additional, to-be-ignored item (visual 'suffix' made up of features from the broader potential memory set) reduced memory for items in the memory array (Ueno et al., 2011a). Participants were also found to recall features of the suffix (Ueno et al., 2011). Regarding sequentially-presented arrays, the suffix reduced performance for the most recently presented object, but not those earlier objects that were sensitive to the effects of cognitive load (Hu et al., 2014). Moreover, the top-down allocation of attention to specific items within a sequence can improve recall for that item (Hu et al., 2016). However, the effect is reduced by suffix interference regardless of the sequential position in which the item was presented (Hu et al., 2016; Hitch et al., 2018).

Impact of anxiety on visual feature binding

Recent evidence has therefore brought a clear theoretical perspective as to the effects of attention on visual working memory that has not thus far been tested with respect to the effects of anxiety on attention. Recently presented memory items overwrite those that have been previously presented and are occupying the focus of attention. However, executive control may be utilised to keep previously presented items within the focus of attention. Regardless of how a representation enters the focus of attention, this is susceptible to interference from further perceptual input. Importantly, executive attention is required for the maintenance of items in working memory to allow their subsequent recall. Perceptual attention grants access to the most recently encountered stimuli without the need for executive control. Perceptual attention may however supersede executive attention in determining which items remain in attentional focus. As aforementioned, highly anxious individuals are believed to be more receptive to perceptual information, while simultaneously being less able to exercise executive control over attention. Thus, when explicitly accounting for both attentional processes in a visual working memory task, a specific deficit could be predicted to emerge in highly anxious participants' visual working memory performance. The overlap in recent theories of visual working memory and the anxiety-attention relationship is striking, but remains under-explored.

Encouragingly, as the theoretical understanding of visual working memory has developed, more studies have been investigating the impact of anxiety in visual-based tasks, albeit mainly those that involve spatial aspects. With perceptual attention shown to drive interference in visual working memory, anxious participants have been shown to be less

efficient at filtering distractors in visuospatial working memory tasks. These findings have emerged from research using tasks derived from Luck and Vogel's (1997) change detection paradigm. In these tasks, participants are presented with a visual memory array followed by a test array, and are asked to indicate whether the arrays are the same or different based on the potential change in a single feature. This task requires the binding of colour and location, or location and orientation. When participants are presented with threatening (Stout et al., 2013) or neutral (Qi, Ding et al., 2014) distractors alongside the to-be-remembered stimuli, high trait anxiety has been associated with reduced late-contralateral delay activity, which is indicative of working memory capacity (Vogel et al., 2005). Other studies, based on Pashler's K formula of filtering efficiency, have since observed behavioural filtering deficits associated with high anxiety in change detection tasks (e.g. Berggren, 2020). There is therefore growing evidence that anxiety is associated with attentional deficits that impact the filtering of irrelevant information from visual working memory, although these have yet to be associated directly with a reduced working memory capacity. Qi, Chen et al. (2014) have however presented evidence that CDA amplitudes in a high trait anxiety group, reached asymptote at memory loads of three items, as opposed to four items in a low trait anxiety group, suggesting a lower overall capacity for visual stimuli. Crucially, a lack of associated behavioural effects suggested that this lower capacity may impact memory efficiency, but not effectiveness, in line with ACT.

Interestingly, though, other studies involving similar tasks and in which additional trait and state factors were accounted for, have found reduced performance effectiveness with high trait anxiety. Jaiswal et al. (2018) found that, compared with participants reporting low trait anxiety and high mindfulness, those reporting high trait anxiety and low mindfulness were less

accurate and sensitive to detecting changes, and also demonstrated reduced capacity.

Mindfulness refers to the ability to regulate and focus attention on a present situation, and

reduce cognitive and emotional distress in the process (Bishop et al., 2004). Effects of trait

anxiety on working memory may therefore only appear if the individual does not – or cannot –

employ strategies to manage feelings of anxiety. Berggren (2020) also observed a deficit in

working memory performance in individuals reporting high trait anxiety, but specifically in a

condition in which apprehension was induced via threat of an aversive noise.

When specifying anxiety further in terms of state and trait, or cognitive and somatic

components, inconsistencies begin to emerge. In particular, recent studies have indicated a

positive association between social anxiety and working memory capacity in tasks where

distractors are not presented (e.g. Moriya, 2018). It is therefore important to consider the

implications of the specific context, or potential range of anxious experiences, when

interpreting effects of anxiety on working memory. Moriya and Sugiura (2012), for example,

suggested that their results may reflect that social anxiety is related to an increased effort to

monitor the surrounding environment. Whereas, Moran (2016) suggested that cultural

differences in manifestations of social anxiety between Western and East Asian populations, or

task-specific factors, may explain these unexpected findings.

It is indeed useful to consider that anxiety may interact with a range of specific factors

to determine cognitive performance. The previous research conducted on anxiety and working

memory, described above, has typically involved tasks that ask participants to make a same-

different judgement that is contingent on the location and/or orientation of objects. In a recent

meta-analysis (Moran, 2016), anxiety has been associated with reliable effects on visuospatial,

but not purely visual, working memory. As such, it remains necessary to determine whether effects of anxiety on visuospatial working memory are related specifically to the spatial characteristics of the task. To our knowledge, only two studies have assessed the impact of anxiety on the binding of non-spatial features.

Wheeler and Treisman's (2002) binding paradigm involves a task in which participants are asked to identify changes in the colour or shape of a single target from a three-item array. Using this paradigm, Moreno et al. (2015) found that worry, a cognitive component of anxiety, was associated with slower response times. However, this was the case regardless of whether a single feature had changed from the memory array to target stage (a nonbinding condition), or if both features had changed (the binding condition), thus suggesting a general reduction in visual working memory performance efficiency. One of our own recent studies was, to our knowledge, the first to assess the impacts of anxiety on visual working memory while directly comparing individual feature vs binding memory performance (Spalding et al., 2020). Furthermore, using the State-Trait Inventory for Cognitive and Somatic Anxiety (Ree et al., 2008), we were able to investigate the relative effects of cognitive vs somatic aspects of anxiety, in addition to state vs trait anxiety. This measure had previously been used by Edwards et al. (e.g. 2015) to successfully demonstrate differential impacts of the anxiety dimensions on attentional control. In our research, while both cognitive and somatic trait anxiety were associated with reduced performance efficiency, the somatic dimension specifically was associated with reduced effectiveness in the most challenging task condition (binding). Therefore, it is not only efficiency that is sensitive to trait anxiety level when considering visual working memory performance. We also found that trait somatic anxiety interacted with state

cognitive anxiety to predict binding effectiveness, showing that it is not only the cognitive

dimension of anxiety, at least at the trait level, that predicts performance (Spalding et al.,

2020).

These studies represent progress regarding the integration of the anxiety literature with

the currently developing understanding of the structure of visual working memory. We propose

that there is value paying careful consideration to the different components of anxiety in the

process. A tentative suggestion, based on our own ongoing work and in light of the existing

literature, is that higher somatic anxiety reflects a reduced ability to successfully inhibit anxious

cognitions that can distract from task performance. This would be in line with the findings of

Jaiswal et al. (2018), who found that high trait anxiety was associated with reduced visuospatial

working memory performance, specifically in conjunction with low mindfulness.

However, there is still scope for progress in terms of methodology. The tasks used by

Moreno et al. (2015) and Spalding et al. (2020) each required the simultaneous encoding of

stimuli. As discussed earlier, the current understanding of a multicomponent visual working

memory which incorporates top-down and bottom-up attention draws heavily on sequential

binding paradigms. These provide an indication of how executive attention may be employed to

maintain items in working memory in light of new perceptual information. These paradigms

have also often involved cued recall as opposed to change detection. One advantage of this

method is that it allows for the analysis of error data, which can potentially indicate the source

of interference (e.g. from a suffix at perceptual level or from the memory set itself at an

executive level). In taking these methods into account, considering specific task manipulations

such as cognitive load, situational stress, and/or stimulus complexity, we can continue to

develop our understanding both of the impacts of anxiety on cognition, as well as the role of

attention within the visual working memory system more generally.

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