Using cognitive tasks to measure clinically relevant cognition in depression and anxiety: Implications for cognitive behavioural therapy

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Declaration

I, Annamaria Balogh, confirm that the work presented in my thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Changes in cognition are thought to contribute to the development and/or maintenance of depression and anxiety disorders. In theory, cognitive behavioural therapy, the most common psychological therapy for depression and anxiety, exerts its effect through modifying cognitive biases observed in patients. Most of the evidence about cognition underpinning depression/anxiety comes from self-reported questionnaires and clinician-rated scales. As an addition to current measurement tools, cognitive tasks could possibly be integrated with clinical practice as more objective and more precise measures of cognition. This, however, requires the development of tasks that measure clinically relevant cognitive processes. As an initial step towards this, in the first two experimental chapters I present results about the association between depression/anxiety symptoms and performance on a battery of cognitive tasks. I found in the first study as well as in the follow-up replication study and mega-analysis that participants with higher depression/anxiety symptom scores were faster at identifying changes in images in a change blindness task. This suggests that change blindness could possibly be used as a behavioural signature for attentional mechanisms underlying depression/anxiety. In the third experimental chapter I examine whether this effect is present in a case-control study. In addition, I investigate metacognitive processes in patients vs. healthy controls, which could have implications for mechanisms underlying psychological therapy. There was no evidence for change blindness and metacognition effects although this final pilot study included in the thesis did not have adequate power to detect effect sizes in the range typically observed in clinical literature. Overall, this thesis presents the research process through which cognitive tasks relevant to the treatment of depression and anxiety could be identified, and makes a case for the potential benefits of integrating

cognitive tasks with psychological therapy as assessment and potentially even therapeutic tools as means to improve personalised treatment.

Impact statement

Impact within academia

This thesis aims to improve our understanding of cognition underlying depression and anxiety disorders and its implications for psychological therapy. The studies presented in the experimental chapters are intended to be disseminated to other scientists, and to the general public, by being published in open access journals in the near future.

Impact for society generally

The work presented in this thesis is as initial step towards bridging the gap between basic cognitive neuroscientific research and clinical practice by using advances in cognitive testing to measure clinically relevant cognition in depression and anxiety.

Integrating cognitive tasks with clinical practice could potentially have a positive impact on treatment outcomes for patients with depression and anxiety in several ways. Measuring patients' cognitive profile more accurately may improve personalised treatment by allowing clinicians to target cognitive behavioural therapy to those who are most likely to benefit from it and also by tailoring therapeutic components to each individual's needs. Furthermore, cognitive tasks could possibly be used as therapeutic tools themselves during the 'psychoeducation' phase of cognitive behavioural therapy by providing engaging and convincing means of improving patients' insight into their own cognitive processes. Finally, it is possible that in the future cognitive tasks will contribute to the scaling up of online psychological treatment provision by offering a cheap and efficient way to aid assessment and direct patients to relevant psychoeducational resources and/or therapy.

Findings presented on the effects of age on cognition as well as depression and anxiety symptoms could contribute to a better understanding of late life emotional disorders and the treatment needs of an ageing population.

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intellectual curiosity that has been a continuous source of motivation and joy in my life. Finally, and above all, my husband, Julian, deserves the warmest of my thanks for *all* that he did over the course of me working on this thesis.

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Note to examiners

The findings from Chapters 3 and 4 have previously been included in the following preprint article:

Balogh, A., Lewis, G., Shafran, R., & Robinson, O. J. (2022, October 21). Change blindness, reward bias, negative affective priming: Exploring individual-level associations between depression/anxiety symptoms and cognition. https://doi.org/10.31234/osf.io/vh5pd

Chapter 1: Introduction

This thesis aims to investigate cognition in depression and anxiety and its implications for psychological therapy. In this introduction I start by defining what I mean by depression and anxiety. I then lay out the role of cognition in these psychological disorders, followed by a discussion of the cognitive aspects of psychotherapy for depression and anxiety, including the potential advantages of integrating cognitive tasks with clinical practice. Finally, I introduce the specific cognitive processes that I explore in this thesis.

1.1 Psychological disorders

Before discussing what we mean by depression and anxiety, it is useful to consider why the construct 'psychological disorder' exists in the first place. It is recognised that altogether roughly one in five of all adults (Kessler et al., 2005; Mcmanus et al., 2009; Wittchen & Jacobi, 2005) and one in ten of all children (Green et al., 2005; Kieling et al., 2011) suffer from significant and persistent psychological pain or impairment in functioning with causes that appear to be psychological. Therefore, it makes sense to conceptualise these cases as 'psychological disorders'. The general consensus, although not universally shared (Lilienfeld & Marino, 1999; Telles-Correia et al., 2018), is that a condition is thought to be a psychological disorder if it consists of 1) significant disturbances in thoughts, feelings and behaviours, 2) these disturbances are likely caused by some form of biological, psychological or developmental dysfunction, 3) they result in significant distress and/or impaired functioning in life, 4) they are atypical, i.e. outside of the culturally approved reactions to certain life events (American Psychiatric Association, 2013; World Health Organisation, 2019).

1.2 Depression and anxiety

The term depression, in clinical use, describes a cluster of symptoms involving significant changes in mood, thinking and behaviour (American Psychiatric Association, 2013; World Health Organisation, 2019). These symptoms must persist for at least two weeks and result in impairment in personal and/or social functioning. Depressive mood is characterised by sadness, irritability or a lack of interest and enjoyment. Cognitive changes include problems with concentration and problem-solving as well as indecisiveness. In addition, a negative thinking style is often present in the form of worthlessness, guilt, hopelessness and suicidal ideation. Behavioural and physical symptoms include appetite and sleep disturbance, tiredness, psychomotor agitation or retardation and social withdrawal.

Anxiety disorders are characterised by excessive worry, hyperarousal and debilitating fear that leads to impaired functioning (American Psychiatric Association, 2013; World Health Organisation, 2019). Individuals with generalised anxiety disorder experience persistent anxiety about several aspects of life, often accompanied by problems with concentration and sleep as well as physical symptoms of dizziness and heart palpitations (Munir & Takov, 2022). Other anxiety disorders are more specific and the most common ones include panic disorder (sudden attacks of extreme fear), social phobia (anxiety about social situations), agoraphobia (fear of leaving one's home or entering open or crowded places) and specific phobias (such as spiders or needles) (Chand & Marwaha, 2022).Although persistent, intense and disruptive anxiety is the primary symptom of anxiety disorders, it is important to mention that anxiety itself is a healthy and normal experience. It is an adaptive human response to potentially threatening situations occurring in the future, meant to protect us from danger by, for example,

alerting us to pay more careful attention in risky situations. Healthy anxiety is temporary and resolves once the stressful event is over. Within the context of normal anxiety, dispositional anxiety, also known as trait anxiety, refers to a relatively stable characteristic that affects an individual's tendency to experience elevated levels of anxiety in a wide range of situations (Spielberger, 1983). Evidence suggests that dispositional anxiety is a risk factor for developing anxiety disorders, particularly generalised anxiety disorder (Gomez, & Francis, 2003). In addition, dispositional anxiety and anxiety disorders may share a common underlying pathology, and it has been suggested that they are dimensional rather than categorical constructs (Endler, & Kocovski, 2001). Cognitively, both are characterised by a tendency to overestimate threat, anticipate negative outcomes and engage in worry. Within this thesis, the term 'anxiety' is used to refer to heightened dispositional anxiety in unscreened samples within the general population and generalised anxiety disorder in clinically screened samples.

Depression and anxiety are the most common psychological disorders in the general population (Layard et al., 2013). At any one time, around 12.9% of adults suffer from varying degrees of depression worldwide (Lim et al., 2018) and around 5-11% satisfy criteria for an anxiety disorder (Baxter et al., 2013). Depression and anxiety have been linked to adverse individual and societal impacts, including a reduced quality of life, physical co-morbidities and increased health care costs (Layard et al., 2013).

Depression and anxiety disorders are highly co-morbid (Kalin, 2020). About 46% of individuals with a lifetime history of depression also have a lifetime history of an anxiety disorder. For anxiety disorders, the lifetime co-morbidity with depression is 20-70%. It is worth noting that the symptoms of 'internalising disorders', i.e., depression

and anxiety, are partially overlapping, and there is a continued debate about whether current diagnostic categories actually represent distinct phenotypes (Waszczuk et al., 2014). The co-occurrence of depression and anxiety has led to the extensive study of the shared and unique aspects of these emotional disorders. These disorders are often jointly referred to as emotional or distress disorders (Clark et al, 1994). Potentially the most widely used theoretical model for discerning the common and distinct aspects of depression and anxiety is the tripartite model (Clark, & Watson, 1991). This framework proposes that symptoms of emotional disorders can be organised in three groups: general distress, anhedonia and anxious arousal. According to this model, negative affectivity, or a general sense of negative mood and emotion, is a shared component between the two disorders. In contrast, low positive affectivity, or a lack of positive mood and emotion, is more specific to depression and only loosely connected to anxiety. Furthermore, physiological hyperarousal is believed to be specific to anxiety.

In addition to co-morbidity and an overlap in symptoms, genetic and neuroscientific research also suggests that depression and anxiety may share common features at a mechanistic level. Research indicates that there is a shared genetic risk among different emotional disorders, with the strongest shared genetic risk found between major depressive disorder and generalized anxiety disorder (Hettema, 2008). Neuroticism, a personality trait or temperament linked to negative emotion, is associated with the development of both anxiety and depression, and there is evidence of shared genetic risk between neuroticism and emotional disorders (Hettema et al, 2006). At the neural level, there are changes in prefrontal-limbic pathways involved in regulating emotions that are commonly found in anxiety and depressive disorders (Etkin, & Schatzberg, 2011; Kovner et al, 20019). These findings align with meta-analyses that have identified shared structural and functional brain alterations in anxiety and major depression. These

alterations primarily affect circuits associated with emotion regulation (Etkin, & Schatzberg, 2011), executive function (Goodkind et al., 2015), and cognitive control (McTeague et al., 2017).

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1.3 Cognitive impairments/biases and their measurement

As mentioned above, in addition to emotional, behavioural and physical symptoms, changes in cognition are characteristic of both depression (e.g., impaired or biased cognitive performance (Nord et al., 2018; Perini et al., 2019), negative thinking style (Sheppard & Teasdale, 1996)) and anxiety (e.g. excessive worry (Hirsch & Mathews, 2012)). These cognitive changes include impairments and biases. Cognitive impairment, broadly speaking, refers to problems with a person's general ability to pay attention, learn, remember, use judgment or make decisions (Morozova et al., 2022). An example of this would be an impaired ability to recall previously memorised words. Cognitive biases, in the context of psychological disorders, are systematic patterns of deviation from the norm (but not clearly an 'impairment' per se, in fact potentially a facilitation) in the way a person processes information at any level, e.g., attention, memory, judgement, decision-making (Beck, 1979; Roy et al., 2008). An example of this would be an increased ability to recall negative (but not neutral or positive) words that were previously memorised.

Studying the cognitive processes underlying depression and anxiety requires appropriate measurement of these processes. The most commonly used measurement tools are self-reported questionnaires and observer- or clinician-rated instruments (Fried et al., 2022; Julian, 2011). Self-reported questionnaires rely on a person's introspection of their own cognitive processes. These can elicit information about a person's inner state directly but are limited by the person's level of insight and individual interpretation of the questionnaire items. Moreover, self-reported questionnaires are not suitable for the direct study of cognitive processes that are under the surface of conscious awareness. Besides self-reported measures, a lot of our current knowledge of cognition in depression and anxiety is derived from third-person observations of patients by clinicians or family members. Although these do not rely on the patient's insight, they only allow mental states to be inferred indirectly from the person's speech or behaviour. In addition, both self-reported questionnaires and third-person observations are subject to biases, such as recall biases, social desirability etc. (Althubaiti, 2016). Nevertheless, they are currently by and large the only available tools to probe cognitive processes that involve complex conscious experiences, such as a tendency to ruminate or worry.

However, rather than asking people (or those around them) to tell us how they tend to respond to things, it is also possible to use cognitive tasks to ask participants to *show* how they respond under certain situations. Cognitive tasks provide various advantages over self-reported and observer-reported questionnaires. They 1) are less subject to biases, 2) can measure more specific cognitive processes, including ones under the surface of conscious awareness (e.g., by using priming paradigms (Elgendi et al., 2018; Goeleven et al., 2006)), 3) can be used to delineate specific processes underlying observed cognitive biases or impairments (e.g., separating the roles of cognitive style and inhibitory control over memory in rumination (Fawcett et al., 2015)), and 4) can be

used in computational modelling to build causal predictions (i.e., testing whether a change in variable X will result in a change in variable Y). However, cognitive tasks are yet to be developed for many of the cognitive processes that are recognised as clinically relevant and are targeted by psychological therapy. For example, there are currently no cognitive tasks measuring an individual's tendency to ruminate (as observed in depression) or to have the belief that worry is a useful strategy for solving problems (as observed in generalised anxiety disorder), which are some of the cognitive processes that I shall explore in this thesis.

It is crucial that all types of instruments used for measuring cognition, including questionnaires and cognitive tasks, are validated based on their psychometric properties (Souza et al, 2017). The primary attributes of measurement tools are reliability and validity. Reliability pertains to the instrument's capacity to yield the same result repeatedly over time and in different contexts. As an example, a test measuring trait anxiety, which is thought to be a relatively stable characteristic of an individual, should show the same result when administered two weeks apart or at home versus in a research setting. Validity signifies the extent to which the measure reflects the construct it is designed to assess. For instance, a cognitive task that is claimed to measure general memory recall ability for words may lack validity if it contains emotionally valenced words. The ability to remember emotional words may be biased by a participant's current mood or underlying psychological disorder, and, therefore, the task would not be an adequate measure of general memory recall for words.

Ensuring psychometric reliability and validity in the domain of cognition underlying psychological disorders poses several challenges. The phenomena studied in this field, such as depression or a tendency to ruminate, tend to be complex and multifaceted.

Measures have to be validated using sophisticated statistical methods to ensure they capture all aspects of such constructs without measuring unrelated constructs. Also, instruments may carry inherent cultural biases that affect reliability and validity over time and in different geographical locations (Swanepoel, & Kruger, 2011).

The replication crisis in psychology and cognitive neuroscience has been widely discussed in recent years (Open Science Collaboration, 2015). One major source of this crisis is inadequate measurement practices, stemming from multiple issues, such as 1) an overreliance on convergent validity (i.e., the extent to which a new scale relates to an established scale that measures the same construct) to establish construct validity, 2) a lack of established reliability in laboratory measures, 3) using measures that are too laborious to administer to achieve large enough sample sizes (Lilienfeld, & Strother, 2020), and 4) poor reliability of cognitive tasks (Zorowitz, & Niv, 2023).

1.4 The role of cognition in depression and anxiety

Cognitive theories of depression and anxiety posit that biases in cognition contribute to the development and/or maintenance of these disorders (Beck, 1979; Segal et al., 2018; Wells, 2011). Although various theories exist that describe the way in which specific cognitive processes are linked to the emergence and maintenance cycle of emotional disorders, they all have in common the idea that our thoughts affect our feelings. In other words, depression and anxiety are not simply triggered by adverse events in the past or possible adverse events in the future but by the perception and appraisal of these events. It follows that, according to cognitive theories of emotion, thoughts also play a role in emotional regulation (Garnefski & Kraaij, 2018). Particular emotional states are assumed to be associated with specific maladaptive cognitive styles as well as cognitive content.

In line with these cognitive theories, there is evidence suggesting that cognitive biases play a causal, rather than merely correlational role, in psychological disorders (Becker, & Vrijsen, 2017). Longitudinal studies suggests that cognitive biases are a risk factor for developing mental disorders, such as panic disorder (Hadwin et al, 2006, Schneider, & Nundel, 2002). It has also been found that cognitive biases serve a mediating role between genetic risk factors and later development of psychological disorders (Klumpp et al., 2014, Vrijsen et al., 2015). Furthermore, research suggests that altering cognitive biases can change emotions and lessen symptoms of psychopathology (Amir & Taylor, 2012; Mathews & MacLeod, 2002).

1.4.1 Depression

It has been found that depression is associated with biased processing of emotional material, which has been studied extensively both in the cognitive neuroscientific literature and in the clinical psychology literature.

Affective processing biases are found in multiple areas of cognitive functioning, such as perception, attention, memory, and the processing of reward and punishment (Roiser et al., 2011). Studies have identified deficiencies in the perception and identification of emotional facial expressions in depression (Persan, & Polivi, 1993).

Depressed individuals have also been found to exhibit negative biases on attentional tasks. People with depression are slower at naming the colour of negative emotional words (Broomfield et al., 2007), while in an affective go/no-go task, they take longer to respond to happy targets (Erickson et al, 2005). Previous research also suggests that depressed patients do not show a bias towards positive emotional material that healthy individuals typically exhibit (McCabe, & Gotlib, 1995). There is also evidence that these negative biases disappear when stimuli are presented very briefly (Kogg et al.,

1993). Therefore, it is possible that negative attentional biases identified at longer stimulus durations might be due to an impairment in disengaging from negative stimuli rather than a tendency to direct more attention to them initially (Roiser et al, 2011).

Memory biases in depression include biases towards negative material (i.e., preferentially remembering negative material) and biases away from positive material (i.e., lack of positive bias for positive material as observed in healthy controls) (Roiser et al, 2011).

Emotional biases in depression also play a role in processing rewards and punishments. It has been suggested that depressed patients have a heightened response to negative feedback on their performance (Murphy et al, 2003). It has been found that responses to rewards and reward-related learning are reduced depressed individuals (Pizzagalli, 2008).

In addition, negative beliefs about the world and the self as well as distorted cognitive thinking styles have been identified in depression (American Psychiatric Association, 2013; Beck, 1979). Beck proposed the "negative cognitive triad" model, in which he posits that individuals with depression have a negative view of themselves (e.g., unworthy, guilty), the world (e.g., hostile, indifferent), and the future (e.g., failure, disappointment, suffering). This negative triad often leads to feelings of worthlessness, hopelessness, and despair.

Biases in cognitive processing of emotional material may be detrimental to regulating negative emotional states and may contribute to sustained negative affect, which is the core feature of depression (American Psychiatric Association, 2013).

1.4.2 Anxiety

There is a robust body of evidence showing that individuals suffering from anxiety disorders exhibit a bias in attention towards threatening information (Williams et al., 1988). This phenomenon has been noted in both clinical and non-clinical populations with high trait-anxiety (Broadbent, & Broadbent, 1998; Craske, & Pontillo, 2005). Another mechanism for attentional bias involves interference effects, where individuals have difficulty focusing on a task when anxious thoughts about a perceived threat are present (Craske, & Pontillo, 2005). For example, a person with social anxiety may struggle to concentrate on a conversation at a social event while experiencing negative thoughts and worry about the unfolding of the event.

In terms of memory biases in anxiety, the findings are inconsistent. In contrast to depressed individuals, some studies have found no memory biases in anxious individuals (Foa et al, 1989; Mogg et al., 1992), while others have reported a free recall mood-congruent memory bias in individuals with high state anxiety compared to controls (Mogg et al, 1987, Watts et al, 1986).

Studies on judgment/interpretation biases suggest that people with anxiety disorders tend to interpret ambiguous situations as negative, resulting in increased salience and availability of threat-related information (Bar-Haim et al., 2007; Muris & Field, 2008). Research has shown that anxious individuals often overestimate the likelihood of negative events, especially those that are self-referent.

The content of maladaptive beliefs in anxiety are future-oriented and relate to a fear of psychological or physical harm and a lack of competence to cope with these situations (Gústavsson et al., 2021).

1.4.3 Shared cognitive biases in depression and anxiety

Fundamentally, depression and anxiety share a cognitive bias toward negative information. In addition, both are characterised by certain maladaptive and distorted thinking styles (Beck, 1979; Beck et al., 2005), such as: 1) all-or-nothing thinking, i.e., viewing things in black and white with no middle ground, 2) overgeneralization, i.e., taking one isolated incident and using it to make broad, generalized conclusions, 3) catastrophising, i.e., expecting the worst possible outcome, 4) personalization, i.e., blaming oneself for events that are not completely one's fault, or interpreting neutral events as personal attacks, 5) mind-reading, i.e. a tendency to believe that one knows what others are thinking, often assuming negative thoughts or judgments about themselves, 6) emotional reasoning, i.e., a tendency to think that because one feels a certain way, it must be true (for example, if they feel anxious about a situation, they might believe the situation is dangerous, even if there is no objective evidence to support that belief).

Negative affective processing biases in depression and anxiety may rely on both heightened 'bottom-up' responses to emotionally significant stimuli and weakened 'top-down' cognitive control mechanisms required to suppress responses (Roiser et al, 2011). These biases are thought to both drive, and then uphold, the pathological symptoms of depression and anxiety (Beck, 1979; Beck et al., 2005). For example, a negative bias in depression may cause a person to be more likely to remember negative life events and discount positive ones. This focus on negative events may, in turn, exacerbate a person’s depressive mood. This may create a vicious cycle in which increasingly low mood results in even stronger cognitive biases which have further negative effects on mood. Similarly, an individual with panic disorder may interpret normal physical symptoms of

anxiety, such as increased heart rate or breathing rate, as dangerous and potentially catastrophic. This perceived threat may further increase anxiety and the associated physical symptoms, possibly resulting in a panic attack, which may reinforce the person's belief that such physical symptoms are uncontrollable and dangerous.

1.4.4 Metacognition in depression and anxiety

All of the cognitive biases discussed so far are about information processing directly in response to events in the external or internal environment, e.g., life events, bodily sensations etc. However, cognitive biases can be one step removed from this. An individual may show certain cognitive biases in the way that they relate to and interpret their own *cognitive processes*. In other words, biases can occur at the level of 'meta-cognition'. Metacognition, according to its broadest definition, is any knowledge or cognitive process that is involved in the monitoring, appraisal or control of cognition. In other words, it is thinking about one's own thinking (Schwarz, 2015). A distinction has been made between implicit metacognition (metacognitive monitoring outside of conscious awareness) and explicit metacognition (Shea et al., 2014). Metacognition studied within the context of depression and anxiety has mostly included explicit metacognitive processes that produce conscious feelings and knowledge about an individual's own cognition (Wells, 2011).

In the clinical psychological literature, metacognition has been explored in cognitive theories of emotional disorders (Wells, 2011). Several aspects of metacognition have been associated with both depression and anxiety, including 1) cognitive self-consciousness (an increased awareness of one's thought processes), 2) low cognitive confidence (in one's memory for places, actions etc.), 3) a belief that worry and rumination are useful cognitive strategies for problem solving, 4) a belief that thoughts

need to be controlled, and 5) negative beliefs about thoughts being uncontrollable and dangerous (Wells, 2000).

Although there exists an extensive clinical literature on the types of cognitive biases in depression and anxiety disorders, our understanding of these cognitive characteristics is still limited. A deeper understanding of these processes, including their component processes and causal relationship to depression and anxiety, is needed to better explain these disorders and improve treatment.

1.5 Psychological therapy in depression and anxiety

Psychological therapy, sometimes referred to as 'talking therapy', is a generic term that encompasses a wide variety of different approaches with distinct theoretical frameworks to treat psychological disorders (Barkham et al., 2021; Roth & Fonagy, 2005). Despite the variation, the common assumption underlying all psychological therapies is that psychological disorders can be effectively treated by exploring the patient's thoughts, emotions and behaviours by dialogue between the patient and therapist.

1.5.1 Cognitive behavioural therapy

Of all psychological therapies, cognitive behavioural therapy (CBT) has the most evidence for its effectiveness to date and it is also the most commonly used in the treatment of depression and anxiety (Butler et al., 2006; Cuijpers et al., 2021). CBT is based on the cognitive theories of emotion described above, i.e., the assumption that cognition affects emotion and therefore plays a role not only in the development and maintenance of psychological disorders but also in their treatment.

Beck's (1979) theory posits that CBT targets maladaptive cognitive processes in emotional disorders by challenging thoughts at three levels: core beliefs, underlying

assumptions and negative automatic thoughts. Core beliefs are fundamental convictions a person has about themselves, others, or the world around them. They are deeply ingrained and often formed in early childhood, influencing the person's perception and interpretation of experiences. Examples of core beliefs in anxiety and depression might include, e.g., “I am not lovable”, “People cannot be trusted," or “The world is dangerous.” Underlying Rules/Assumptions, also referred to as intermediate beliefs, are strategies that people use to in their lives, often derived from core beliefs. For example, a person with the core belief “I am not lovable” might have an underlying assumption that “If I please everyone, then people will like me.” Negative Automatic Thoughts are spontaneous, unfiltered thoughts that occur in response to specific situations, influenced by core beliefs and underlying assumptions. They may focus on perceived threats, failures, or negative information. For instance, if a person failed to please someone, a negative automatic thought could be “they don't like me because I'm unlovable.”

In addition, CBT interventions aim to provide insight into and change patients’ negative thinking styles and cognitive distortions (Dozois, & Beck, 2008; Kennerley, 2016). These distortions, characteristic of depression and anxiety, include 1) all-or-nothing thinking (i.e., seeing things in black and white categories), 2) overgeneralisation (i.e., drawing a broad conclusions based on a single incident),3) mental filer (i.e., paying selective attention to negative details),4) jumping to conclusions (i.e., making negative interpretations without actual evidence, including “mind reading” (assuming the thoughts of others) and “fortune telling” (predicting future events), 5) catastrophising, 6) personalisation (i.e., attributing external events to oneself without evidence that one is the cause), and many others.

Supporting the theory that CBT exerts its effect through changing maladaptive cognition, research has shown that CBT may be effective in modifying underlying cognitive biases in emotional disorders, particularly attentional biases to threat in anxious patients. For instance, in two studies, CBT has been effective in modifying implicit associations and attentional bias in individuals with panic disorder (Reinecke et al., 2013, Teachman et al., 2008). This change in attention was also linked to better therapy outcomes.

CBT uses both cognitive and behavioural methods to relieve symptoms of depression and anxiety (Kennerley, 2016) but here I focus on cognition only. Maladaptive cognitive styles and content are addressed through three main methods. 1) During psychoeducation (Motlova et al., 2017), patients are given general information about the characteristics of their psychological disorder, including the particular thinking styles associated with it, in order to help them understand more about their own condition, its maintenance cycle and ways to break the maintenance cycle. For example, a therapist may explain to a person with social anxiety that this condition is characterised by an increased focus on and fear of negative evaluation by others as well as a belief that the person is not able to emotionally tolerate such negative evaluation. As a result of these thoughts, the patient may avoid social situations, which, in turn, would prevent them from disconfirming those unhelpful beliefs. 2) Cognitive restructuring (Clark, 2013) uses various techniques, such as thought diaries, that help patients gain insight into, notice and change their unhelpful thinking patterns. For instance, the patient with social anxiety may be instructed to write down negative thoughts they had during social situations that day, and to rate on a scale from 1 to 10 how much they believe those thoughts. For each thought, they may then identify the corresponding negative thinking pattern, such as mind-reading (i.e., inferring others' negative opinions about oneself

without available evidence). Finally, the patient may be invited to list objective evidence for and against each thought and to rate again their degree of belief in those negative thoughts. 3) Behavioural experiments are planned activities to test the validity of maladaptive beliefs that contribute to the disorder (Rouf, 2004). For example, the person with social anxiety may believe that if she spills coffee on her shirt in public, people around her will laugh at her, which will make her feel more embarrassed than she can tolerate. A therapist may arrange a behavioural experiment to test whether this belief is accurate by asking the patient to 1) write down how likely she thinks it is that others will laugh at her and how bad she expects to feel as a result on a scale from 1 to 10, then to 2) go out in public and spill coffee on her shirt, and finally to 3) write down whether others around her laughed and, if so, how bad she felt as a result.

Since its inception, numerous CBT protocols have been developed to target specific cognitive and behavioural aspects related to specific disorders. These specialized treatments are similar in certain general aspects, such as an emphasis on therapeutic alliance between patient and therapist, collaborative empiricism (i.e., therapist and patient working together to examine the evidence supporting or refuting the patient's beliefs), Socratic questioning (i.e., the therapist posing a series of graded questions as a means to guide the patient toward therapeutic goals), and broad categories of interventions described above, such as psychoeducation and cognitive restructuring. It is important to note, however, that CBT protocols are tailored to each disorder as well as context (e.g., individual vs group, in-person vs online, working directly with a child vs parent-led). As such, different types of CBT differ in the interventions and techniques used, and there is no one single "CBT".

1.5.2 Cognitive behavioural therapy and metacognition

In recent years, it has been proposed that a (if not 'the') key underlying cognitive mechanism of psychological therapies in general, and cognitive behavioural therapy in particular, is metacognition. In other words, it may be that in addition to changing cognitions at the level of core beliefs, assumptions and negative automatic thoughts (as CBT is often described (Kennerley, 2016)), individuals undergoing therapy change the way they relate to those thoughts or to their thoughts in general (and potentially change their content over time as a result, but the emotional change could possibly occur before the content is changed).

Metacognitive Therapy, which uses the principles of CBT with an explicit emphasis on metacognitive processes has been found to have a positive impact on various facets of maladaptive metacognition linked to both depression as anxiety, as discussed above, namely 1) cognitive self-consciousness, 2) low cognitive confidence, 3) a belief that worry and rumination are useful cognitive strategies for problem solving, 4) a belief that thoughts need to be controlled, and 5) negative beliefs about thoughts being uncontrollable and dangerous (Wells, 2000). Two meta-analytic reviews of metacognitive therapy for depression and anxiety found a large effect size for reduced maladaptive metacognitions from pre- to posttreatment, which also lasted from pretreatment to follow-up (Normann et al., 2014, Normann, & Morina, 2018). Furthermore, metacognitive therapy was also effective in reducing depression and anxiety symptoms. However, further evidence is needed with regard to the temporal causality between symptom changes and metacognitive changes in order to discern the role of metacognitive change in symptom. Nevertheless, changes in metacognition during metacognitive therapy and the associated reduction in symptoms are consistent

with the theory that maladaptive metacognitive beliefs and strategies maintain psychological disorder and that recovery may be achieved through addressing these metacognitive processes (Wells, 2000).

In addition to improving maladaptive metacognitive beliefs observed in depression and anxiety, CBT has also been proposed to exert its effect through a mechanism referred to as "metacognitive awareness" or "decentering" (Beck et al., 1979; Teasdale, 1999). Decentering refers to an individual's ability to observe thoughts and feelings as events arising and subsiding in the mind rather than personally identifying with them (Safran & Segal, 1990). Distancing oneself from their thoughts and emotions and experiencing them as objective occurrences that come and go is likely to facilitate various aspects of CBT, such an emphasis on the idea that "thoughts are not facts", putting less weight on thoughts and emotions arising from cognitive distortions (e.g., catastrophising or black-and-white thinking), and being able to participate in emotionally challenging behavioural experiments (e.g., exposing oneself to a feared situation). Previous experimental studies have found that decentering decreases distress (e.g., Davis et al., 2011) and reduces the believability of negative thoughts (e.g., Masuda et al., 2010). Furthermore, it has been shown that decentering may increase over the course of CBT, which is also associated with better CBT outcomes (Hayes-Skelton, & Lee, 2019). In line with our limited knowledge of how psychological therapies work, evidence suggests that only about half of the patients treated with CBT for depression and anxiety recover (NHS Digital, 2019). A better understanding of the cognitive processes underlying depression and anxiety disorders as well as therapeutic interventions may enable us to target CBT more effectively to those who are most likely to benefit from it and also to tailor the therapeutic components of CBT to each individual based on cognitive characteristics.

1.6 Cognitive tasks and psychological therapy

Despite the existence of clinical models about the maintenance cycle of mood and anxiety disorders and the intuitively appealing rationales for how the above-mentioned cognitive interventions interrupt these vicious cycles, it is still poorly understood through which mechanisms cognitive behavioural therapy exerts its effect. Despite a clear role of cognitive processes in cognitive behavioural therapy on one hand and progress in cognitive testing in recent years on the other, there is surprisingly little work done on incorporating cognitive tasks into psychological therapy. Indeed, there is very little empirical work on assessing cognitive processes posited to play a role in the maintenance of depression and anxiety disorders and testing whether they change as a result of CBT. However, a pre-requisite to this is to be able to measure these cognitive processes accurately.

One possibility is that we could use the results of contemporary cognitive testing to target CBT to individuals who are likely to respond to it. Another possibility is that we would be able to personalise treatment based on individual performance on cognitive tasks during assessment. Finally, cognitive tasks could be incorporated into the psychoeducation or behavioural experiment components of CBT as a way of providing patients with demonstration of, and insight into, their own cognitive biases.

1.7 Premise of this thesis

In this thesis I explore the impact of anxiety and depression symptoms on cognitive functions as a first step towards integrating a better understanding of cognition into psychological therapy. Specifically, I designed and collected online data on tasks that potentially measure clinically relevant cognitive processes, with the intention to 1) investigate understudied cognitive phenomena that could have implications for therapy

outcomes, such as an ability to bring previously unnoticed information into conscious awareness or to improve insight into one's own cognitive functioning, 2) identify cognitive tasks that could be used to provide a behavioural signature of complex cognitive processes, such as rumination and worry, that play a crucial role in mood and anxiety disorders but are currently only measured through self-reported questionnaires, and 3) design engaging cognitive tasks that could potentially be integrated with CBT as convincing therapeutic tools.

1.8 Specific cognitive processes being studied in this thesis

As the usefulness of cognitive tasks in psychotherapy for depression and anxiety is largely unexplored, there is a wide range of tasks measuring cognitive biases potentially related to treatment outcomes to be studied. In this thesis, I focus on four cognitive tasks that cover a broad spectrum of cognitive processes.

1.8.1 Change blindness task

Change blindness refers to a failure to notice changes in the visual environment which become obvious once attention is directed towards them (Rensink et al., 1997). The change blindness task used in this thesis measures this phenomenon by presenting images of scenes flickering on and off the screen with a brief masking stimulus (a grey background) in between flickers. In each image, one obvious but hard-to-notice change occurs as the image flickers on and off the screen. Participants are instructed to indicate as soon as they notice the change in the image and then to point out where the change happened (either by choosing from a list or by clicking on the location of the change, in different variants of the task). A longer reaction time in noticing the change corresponds to increased change blindness.

Since change blindness paradigms are thought to measure attentional biases towards concern-related cues (Moss et al., 2011), they could potentially be used to reveal attentional mechanisms linked to depression and/or anxiety. Both disorders exhibit alterations in attentional control in the form of difficulty in disengaging from negative or threatening stimuli coming either from the external environment or from internal bodily sensations and thoughts (Eysneck, & Derakshan, 2011; Mennen et al., 2019). This negative attentional bias can manifest differently across disorders. Research suggests that individuals with depression show an attentional bias towards punishment, sadness as well as negative self-referential information (Leyman et al., 2007, Nejad et al., 2013). In addition, depression has been associated with reduced attention to rewards and social information (Enneking et al., 2018). Negative attentional bias in anxiety disorders manifests as heightened attention towards threat-related stimuli and an increased tendency to scan the environment for potential threats, often referred to as hypervigilance (Bar-Haim et al., 2007). Conversely, there is also evidence anxiety is associated with attentional avoidance of threat, which refers to the tendency to initially attend to threat but then disengage from threatening stimuli that are presented for a prolonged period (Derryberry, & Reed, 2002).

Although there is a paucity of research on change blindness in the context of depression and anxiety, this paradigm could provide several advantages relative to other cognitive tasks when studying attentional biases in these disorders. Change blindness tasks are excellent at simulating real-world situations where an individual may fail to notice changes in their environment due to the limitation of their attention. Therefore, change blindness tasks could help us understand how attentional biases in depression and anxiety manifest in naturalistic contexts.

In addition, change blindness paradigms may inform our understanding of attentional processes in depression and anxiety in the context of the 'predictive processing' framework of the brain (Bubic et al., 2010; Friston, & Stephan, 2009). According to the predictive processing framework of cognition and perception, the brain is continually making predictions (often referred to as 'priors') about the state of the world and then updating those predictions based on prediction errors produced by incoming sensory information (i.e., mismatches between prediction and sensory data). It postulates that the brain operates under a "predict first, correct after" principle. In other words, to a large extent, we see what we expect to see. This framework could potentially explain why we often fail to notice significant changes in visual scenes when the change occurs during a visual disruption, such as a blink, a saccadic eye movement or a masking stimulus. The brain may "fill in" the scene during the disruption based on its predictions, which do not include the change. Predictive processing may also shed light on the finding of relatively stable individual differences in change blindness (Andermane et al., 2019). Those with increased change blindness may put higher weight on their predictions and/or have less robust predictions resulting in more imprecise prediction errors and/or put lower weight on prediction errors. Conceptually, this difference could potentially be understood as a difference in the allocation of attention toward prediction about the state of the world versus incoming sensory data.

Measuring change blindness in the context of depression and anxiety could provide important insights into the cognitive underpinning of these disorders. To the best of my knowledge, there is no previous study investigating change blindness in depression and anxiety. Therefore, the studies described in this thesis are highly exploratory and the initial hypotheses run in both directions. Increased change blindness in depression and/or anxiety could imply that these disorders are associated with a reduced ability to

update predictive models in light of new information. This could potentially drive the persistent negative bias and rumination/worry observed in depression and anxiety. It would also be consistent with the concept of "intolerance of uncertainty", which is a common feature of trait anxiety and anxiety disorders (Wells, 2009). Conversely, a reduced change blindness (i.e., a better ability to notice changes in the environment) could give us a clue that depressed/anxious individuals have less stable predictions about the state of the world and/or put a greater weight on their prediction errors. This could potentially be linked to the development and/or maintenance of these disorders by causing individuals to perceive the world as more volatile and dangerous as well as to be less confident in themselves, including their thoughts and actions.

In addition to deepening our understanding of the cognitive processes underlying depression and anxiety, the change blindness task could potentially provide further clinical utility in choosing treatment. It is possible that a better ability to detect changes in the environment could be used effectively in CBT which involves instructing patients to bring attention to previously unnoticed features in the environment during behavioural experiments as well as to thoughts and internal processes that usually lie outside of conscious awareness (Morris, 2021). Conversely, a difficulty in noticing changes may impede progress during CBT. This would be consistent with previous research showing that individuals with higher levels of dysfunctional attitudes and cognitive beliefs, which could potentially correspond to stronger priors and a reduced ability to update predictions about the world, have a poorer CBT outcome relative to individuals with lower levels (e.g., Hamilton & Dobson, 2002; Jarrett et al., 1991). As such, it could be the case that performance on the change blindness task could inform us about CBT outcomes at the individual level.

For the reasons mentioned above, in this thesis I was primarily interested in investigating whether there is a difference in change blindness *per se* associated with depression and/or anxiety. To do this, I designed a change blindness task without manipulating emotional valence in order to dissociate the change blindness effect from the effect of known attentional biases related to emotion in these disorders. Nonetheless, conducting exploratory online studies using this paradigm could also inform future research about the feasibility and usefulness of using the change blindness task as a measure of emotional attentional biases related to depression/anxiety.

1.8.2 Metacognition task

This task measures metacognitive efficiency, i.e., the extent to which a person's subjective confidence judgements in their own performance tracks how well they perform on the task objectively (Fleming & Lau, 2014). It is possible that an individual's level of insight into their own cognitive processes could inform how likely they are to benefit from CBT. I hypothesise that that both depression and anxiety will be associated with lower metacognitive confidence (Barrientos et al., 2022; Culot et al., 2021; Reyes et al., 2020). Previous research yielded mixed findings on whether these disorders are associated with a better or worse metacognitive efficiency (Rouault et al., 2018), i.e., the ability to track fluctuations on one's performance. Therefore, I do not have a strong hypothesis. Lower metacognitive efficiency would be consistent with a generally impaired cognition observed in depression and anxiety (Nord et al., 2018; Perini et al., 2019). However, increased metacognitive efficiency, i.e., a keen awareness of fluctuations in one's performance could be associated with the development and/or maintenance of depression (specifically, symptoms of low self-esteem and feelings of inadequacy) and/or anxiety (specifically, symptoms of underestimating one's ability to

cope and intolerance of uncertainty). My study aims to provide further clarity on this. In addition to measuring metacognitive efficiency in these disorders, it is an open question whether metacognitive efficiency can be voluntarily improved through instruction. If so, it would have promising implications for the potential of psychological therapy, which largely relies on developing insight into one's own cognitive processes. I used this task to explore this question. To my knowledge, no study has investigated the effect of voluntary effort over metacognitive efficiency without manipulating other task variables (such as increasing the threat of punishment (Culot et al., 2021). Therefore, I do not have a strong hypothesis about the direction of the relationship or lack thereof. It is tempting to assume that just like many other cognitive exercises, such as adding up a series of two-digit numbers, metacognitive efficacy could be improved through voluntary effort. However, it does not seem intuitively obvious to me that the same principle applies when reflecting on one's cognitive processes after the fact. Metacognitive efficiency could be impervious to voluntary effort. Indeed, it could also be the case that an extended effort to reflect on one's cognitive performance could further remove the individual from their subjective experience of how they solved the task, which could lead to worse metacognitive efficiency (i.e., reduced insight).

In addition to change blindness and metacognition tasks, I also explore two control tasks in the thesis. These tasks, which previous research has already found to be associated with depression and anxiety and may themselves be clinically valuable, are included as replications of previous findings and positive controls that help us interpret potential null results with regard to other cognitive tasks. I.e., if in our study we fail to find a relationship between the control tasks and depression and anxiety symptoms, we may suspect that our null result is not strong due to poor data quality or non-representative sample in our study. Both tasks explore aspects of negative affective bias:

1.8.3 Reward bias task

Prior studies suggest that depression and anxiety are associated with a pessimistic tendency, i.e. an expectation of negative events or a lack of positive events happening in the future (Aylward et al., 2019; Love & Robinson, 2020; Pizzagalli et al., 2008). In this task, participants are asked to evaluate whether an ambiguous stimulus is closer to a stimulus resulting in a higher reward or to one resulting in a lower reward. This is a measure of a reduced tendency to anticipate future rewards in individuals with depression and anxiety (Daniel-Watanabe et al., 2022). In line with this, my hypothesis is that individuals with higher self-reported depression and trait anxiety scores will show a reduced reward bias.

1.8.4 Negative affective priming task

Two common cognitive features of depression and anxiety are rumination and worry (Beck, 1979; Beck et al., 2005), i.e., an excessive focus on past or future negative events. The negative affective priming task is used to measure the ability to ignore irrelevant emotional (in this case negative) stimuli (Goeleven et al., 2006). The extent to which an individual is able to ignore negative information may be related to tendencies of rumination and worry, i.e., people who have a hard time disengaging from irrelevant negative emotional stimuli may be more likely to get caught up in rumination and worry. Based on rumination and worry being one of the defining symptoms of depression and trait anxiety/anxiety disorders, respectively, I hypothesise that higher depression and trait anxiety scores will be associated with a reduced negative affective priming effect, i.e., an impaired ability (or reduced tendency) to disengage from irrelevant negative information.

1.9 Conclusion

In summary, evidence suggests that cognitive biases play a key role in the development and maintenance of mood and anxiety disorders. Psychological therapies, most notably cognitive behavioural therapy, are assumed to exert their effect by changing maladaptive cognitive styles and content. Cognition is mostly measured through subjective self-reported and observer-reported questionnaires in clinical practice. Cognitive tasks are increasingly used to delineate specific cognitive processes in an objective manner but are yet to be integrated with clinical practice. Understanding more about the cognitive biases underlying depression and anxiety in this way could potentially improve therapy outcomes by targeting CBT to those who are most likely to respond to it and by personalising treatment. To further this aim, in this thesis I focus on four cognitive tasks that could be relevant to therapy outcomes and explore their relationship to depression and anxiety symptoms.

1.10 Summary of the thesis chapters

In Chapter 2, I introduce the cognitive tasks and symptom questionnaires used throughout the studies included in the thesis. Chapter 3 is about my first cross-sectional study in which I investigated the association between depression and anxiety symptoms and individual-level task performance on the change blindness, reward bias and negative affective priming tasks in an unscreened online sample. Chapter 4 includes a replication of the change blindness effect found in my first study as well as a mega-analysis in which I looked at the change blindness effect in the pooled data from the original and replication studies. In Chapter 5, I present my follow-up case-control study on change blindness and metacognition in healthy controls and a screened clinical sample of

individuals with depression and/or generalised anxiety disorder. Finally, I discuss the general findings, implications and directions for future research in Chapter 6.

Chapter 2: Experimental methods

In this chapter I provide an overview of the methods used in the thesis to avoid excessive duplication in the individual chapters.

2.1 Online data collection

Participants were either fully anonymous and recruited online on the Prolific (www.prolific.co) recruitment platform (Chapters 3 and 4) or known to the researchers through telephone pre-screening but still remote (Chapter 5). In the two cross-sectional studies described in Chapters 3 and 4, the majority of participants, 60%, were based in the UK, with a further 31% based in continental Europe, and the remaining 9% based elsewhere, including South Africa, North and South America, Australia and the Middle East. Participants in the clinical case-control study described in Chapter 5 were all based in the UK. Questionnaires and cognitive tasks were hosted online on the Gorilla (www.gorilla.sc) platform and presented remotely on participants' desktop screens.

2.2 Questionnaires

Questionnaires were used to establish common symptoms of mental ill health.

2.2.1 Beck Depression Inventory-II (BDI-II)

The BDI-II (Beck et al., 2011) is a 21-item self-reported questionnaire that measures symptoms of depression. We did not include the 9th item, in order to avoid inquiry about suicidal thoughts without means of intervention in online studies. Participants are asked to choose from a group of four statements the one that they think best describes them. The statements are quantised from 0 to 3 and these scores are added to obtain a total score. E.g., "I don't feel particularly guilty": 0, "I feel guilty a good part of the time": 1,

"I feel quite guilty most of the time": 2, "I feel guilty all of the time": 3. In our 20-item version of the questionnaire (9^{th} item excluded), scores range between 0 and 60, with higher scores indicating more severe symptoms of depression.

2.2.2 State-Trait Anxiety Inventory - trait subscale (STAI-T)

The STAI-T (Spielberger, 1983) is a 20-item self-reported measure of trait anxiety symptoms (i.e., a stable tendency to experience anxiety). Participants are asked to respond to a series of statements (e.g., "I feel nervous and restless") on a 4-point Likert scale of "Almost never", "Sometimes", "Often, "Almost always". Answers are coded from 1 to 4 and then summed to obtain a total score between 20 and 80, with higher scores corresponding to higher levels of trait anxiety.

2.2.3 Metacognitions Questionnaire (MCQ-30):

The Metacognitions Questionnaire (MCQ-30) (Wells & Cartwright-Hatton, 2004) is a 30-item self-reported measure of metacognitive processes that are thought to be associated with emotional disorders (Wells, 2000). Participants respond by indicating the extent to which they agree with each statement listed in the questionnaire on a 4-point Likert scale coded from 1 to 4 ("Do not agree": 1, "Agree slightly": 2, "Agree moderately": 3, "Agree very much": 4). The scale includes the following five 6-item subscales: positive beliefs about worry (e.g., "Worrying helps me to avoid problems in the future."), negative beliefs about the uncontrollability and danger of worry (e.g., "I could make myself sick with worrying."), cognitive self-consciousness (e.g., "I monitor my thoughts."), beliefs about the need for control of thoughts (e.g., "I should be in control of my thoughts all of the time.") and lack of cognitive confidence (e.g., "I do not trust my memory"). Scores on the subscales range from 6 to 24. Total scores ranging from 30 to 120 are obtained by adding up scores from all subscales. Higher scores

indicate higher levels of maladaptive metacognitions, according to the metacognitive model of emotional disorders (Wells, 2000).

2.2.4 Revised Clinical Interview Schedule (CIS-R)

The CIS-R (Lewis et al., 1992) is a standardised interview measuring the severity and nature of psychiatric symptoms by generating a total score as well as categorical diagnoses according to ICD-10 criteria of the following: depression, panic disorder, generalised anxiety disorder, agoraphobia, social phobia, specific phobia, mixed anxiety and depression, obsessive-compulsive disorder, mild generalised anxiety disorder, mild neurosis (i.e., a clinically significant level of distress based on total CIS-R score of 12 or above but without fulfilling criteria for any of the diagnoses). Participants are asked a series of forced-choice questions, (e.g., "On how many days have you felt irritable, short tempered or angry in the past seven days?": "None", "Between one and three days", "Four or more days"). The CIS-R has 14 main sections which measure somatic symptoms, health worries, panic, compulsions, obsessions, phobias, irritability, worry, anxiety, concentration, fatigue, sleep, depression and depressive thoughts. Scores range between 0 and 4 for each section, with the exception of the section on depressive thoughts which ranges from 0 to 5. Total CIS-R scores range from 0 to 57, with higher scores indicating more severe neurotic symptoms. A score of 2 or more on any individual section is considered significant. A total score of 12 or more indicates a clinically significant level of distress. If the score of any symptom is at least 2, primary and, if present, secondary diagnoses may be determined.

2.3 Cognitive tasks

2.3.1 Reward bias task

The reward bias task is a measure of bias in the context of anticipated rewards. Prior studies suggest that individuals with depression have a "negative bias" or a "pessimistic tendency", i.e., they are less likely to anticipate high rewards (Daniel-Watanabe et al., 2022; Love & Robinson, 2020).

The task is illustrated in **Figure 2.1**. Participants were instructed to maximise their earnings in a 2-alternative forced choice task. The task had a training and a main phase. In the training phase, participants were shown horizontal and vertical lines with corresponding high or low rewards (£4 or £1). They were instructed to press a button ('z' or 'm') after the appearance of each line to receive a reward contingent on pressing the correct button. The stimulus-response contingency was 100%, and it was learned by participants on a trial-and-error basis. The line orientation and corresponding reward was counterbalanced across individuals. The training phase had 20 trials (10 for both types of stimuli).

In the main phase of the task, participants were also shown 45° diagonal lines as intermediate stimuli. These were randomly followed by a high or low reward (i.e., stimulus-response contingency was 0.5). Therefore, pressing the button corresponding to high reward after an intermediate stimulus was an 'optimistic response'. The main phase had 120 trials (40 for each type of stimulus).

In each trial, the stimulus was shown for 1000 ms, followed by a fixation cross for 750 ms. Participants were allowed to respond from the beginning of stimulus presentation

and were given one of the following types of feedback for 3250 ms: “Correct, win £1”, “Correct, win £4”, “Timeout for incorrect response”, “Too late, timeout!”.

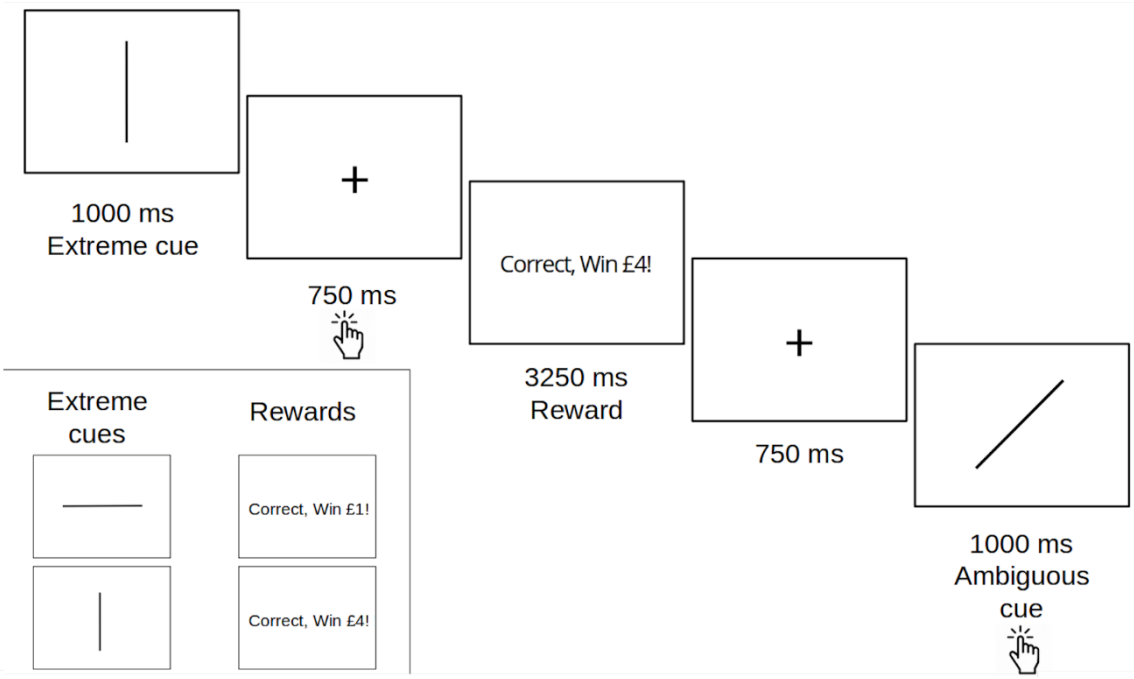

Figure 2.1 Reward bias task. Phases: In the training phase, participants were shown only extreme cues (vertical and horizontal lines) with corresponding high or low rewards (£4 and £1). Participants were instructed to respond by pressing 'z' or 'm' keys in order to win a reward contingent on pressing the correct key. Stimulus-response contingency was 100%, learned on a trial-and-error basis. Participants were given feedback after each trial ("Correct, win £1", "Correct, win £4", "Timeout for incorrect response", "Too late, timeout!"). In the main phase, participants were also shown intermediate stimuli (45° diagonal lines) that were randomly followed by a high or low reward (i.e., 50% contingency). Sequence: A cue appeared on the screen for 1000 ms followed by a fixation cross for 750 ms. Participants were able to respond from stimulus onset. Next, a feedback screen was shown for 3250 ms.

2.3.2 Negative affective priming task

In this task, participants are asked to ignore irrelevant negatively valenced emotional stimuli (Goeleven et al., 2006). Rumination and worry are key cognitive symptoms of anxiety and depression (Beck, 1979; Beck et al., 2005), and it is possible that one underlying mechanism of these symptoms is an impairment in the inhibition of processing irrelevant negative information (Goeleven et al., 2006).

The task is illustrated in **Figure 2.2** and **Table 2.1**. It consisted of pairs of prime-probe trials (i.e., a prime trial followed by a probe trial, indistinguishable for the participants). In each trial, two words were shown on the screen: a target and a distractor. Targets and distractors were indicated by their colour (red vs. blue). Participants were asked to evaluate the valence (negative vs. neutral) of the target word by pressing buttons 'f' or 'j'. Participants were also instructed to ignore the distractor word. The response cue (red vs. blue) and the key assignment were counterbalanced between subjects.

The task had four conditions. In the experimental condition, a negative prime-distractor was followed by a negative probe-target. In the control condition, a neutral prime-distractor was followed by a negative prime-target. In order to prevent learning effects, there were filler trials for both the experimental and control conditions, as detailed in **Table 2.1**. The sequence of conditions and the spatial position (top vs. bottom) of the target and distractor words were randomised.

The task had a training phase with 20 trials. Following this, there were three blocks of 32 prime-probe trials (96 prime-probe trials in total), with 8 prime-probe trials in each condition (24 prime-probe trials in each condition in total). The same set of words were used across the three blocks, but the word pairs were randomised in each block. 32

negative and 96 neutral words were chosen from the affective norms of valence list created by Warriner et al., 2013. Only words with 4-6 letters were chosen.

Each trial consisted of a fixation cross shown for 250 ms followed by the target and distractor words for 3000 ms.

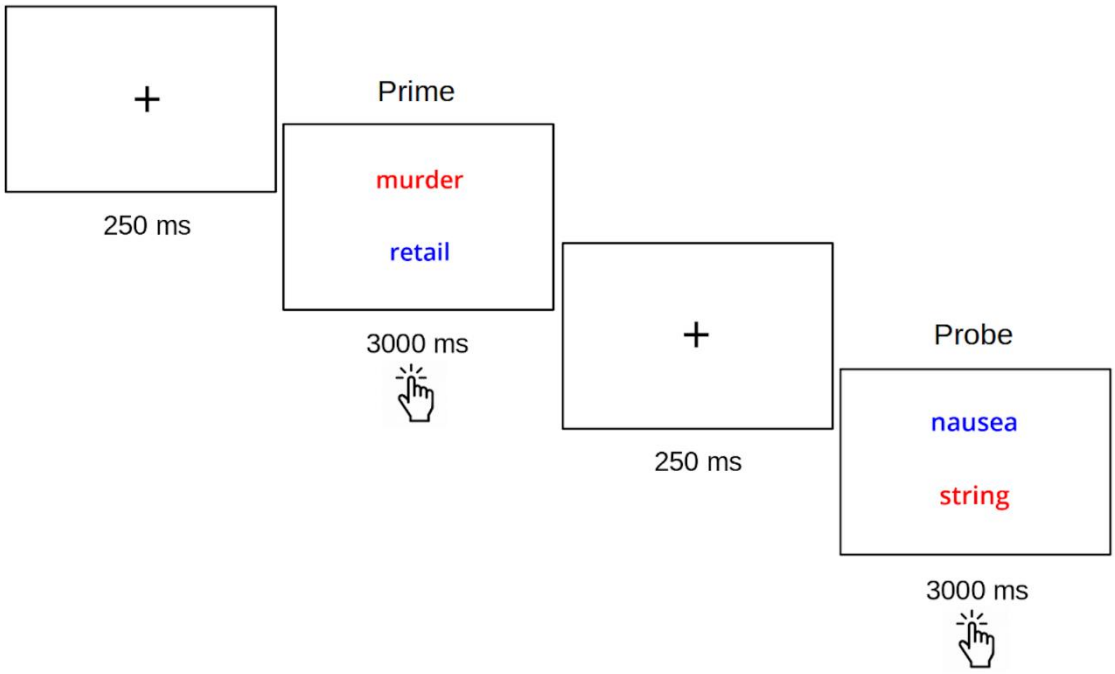

Figure 2.2 In each trial, two words were shown on the screen: a target and a distractor, indicated by their colour. Participants were instructed to ignore the distractor word and evaluate the valence (negative vs. neutral) of the target word by pressing 'f' or 'j' keys. Trials began with a fixation cross shown for 250 ms followed by target and distractor words for 3000 ms. Prime and probe trials were indistinguishable for participants.

Condition	**Prime**		**Probe**	
	Target	**Distractor**	**Target**	**Distractor**
Experimental	Neutral	Negative	Negative	Neutral
Experimental-Filler	Neutral	Negative	Neutral	Neutral
Control	Neutral	Neutral	Negative	Neutral
Control-Filler	Neutral	Neutral	Neutral	Neutral

Table 2.1 Conditions of negative affective priming task. In the experimental condition, the valence of the prime distractor (negative) matched the valence of the probe target (negative). In the control condition the prime distractor (neutral) and the probe target (negative) did not match in valence. Filler trials were included for both experimental and control conditions in order to prevent learning effects.

2.3.3 Change blindness task

This task measures the time it takes to notice changes in visual stimuli. It has been proposed to be a measure of attentional bias towards concern-related cues (Moss et al., 2011). Although previous research suggests that depression and anxiety are characterised by attentional biases (Bar-Haim et al., 2007; Mennen et al., 2019), there is a paucity of research on the relationship between depression and anxiety symptoms and change blindness.

The task is presented in **Figure 2.3**. Participants were shown pairs of almost identical images (image A and image B), with one distinct change between the two images. Images A and B alternated on the screen. Each image was displayed for 2000 ms, with a mask appearing between them for 250 ms. Each pair was shown for up to 45 seconds.

In the first version of this task (Chapter 3), participants were instructed to press a button once they noticed the difference within pairs of images (**Figure 2.3/A**). Once they pressed the button, they were asked to indicate the difference they noticed from a list of 5 options. If they did not press the button in 45 seconds, a brief timeout screen was shown before the next image was displayed. The task consisted of 21 pairs of images. All images were social (i.e., they included at least one human), and all changes appeared in the surroundings.

In the follow-up studies (Chapters 4 and 5), we modified our original change blindness task by instructing participants to click with their mouse where the change in the image occurred as soon as they noticed it (**Figure 2.3/B**). This was to improve the sensitivity of the task by reducing the possibility that participants could be 'correct' by chance. If their response was correct (determined by whether they clicked within the smallest rectangle that can be drawn around the area that changed in the image), they were

moved on to the next stimulus. If their response was incorrect, there was a 12-second timeout period during which “Timeout for incorrect response” was displayed on the screen. The task consisted of a total of 63 pairs of images, presented in a random order. Three types of stimuli (21 of each) were shown: 1) images in the “surroundings” condition were scenes showing humans, with changes happening in the surroundings (same condition as in the first version of the task), 2) images in the “humans” condition were scenes showing humans, with changes happening in humans, 3) images in the “non-social” condition were scenes without humans.

In our second study (Chapter 4), following completion of that task, participants were asked to reflect on their behaviour after they spotted the change in the images by answering on a 4-point scale whether they never: 0, sometimes: 1, often: 2, always: 3 double-checked if they were correct before clicking on the change in the images.

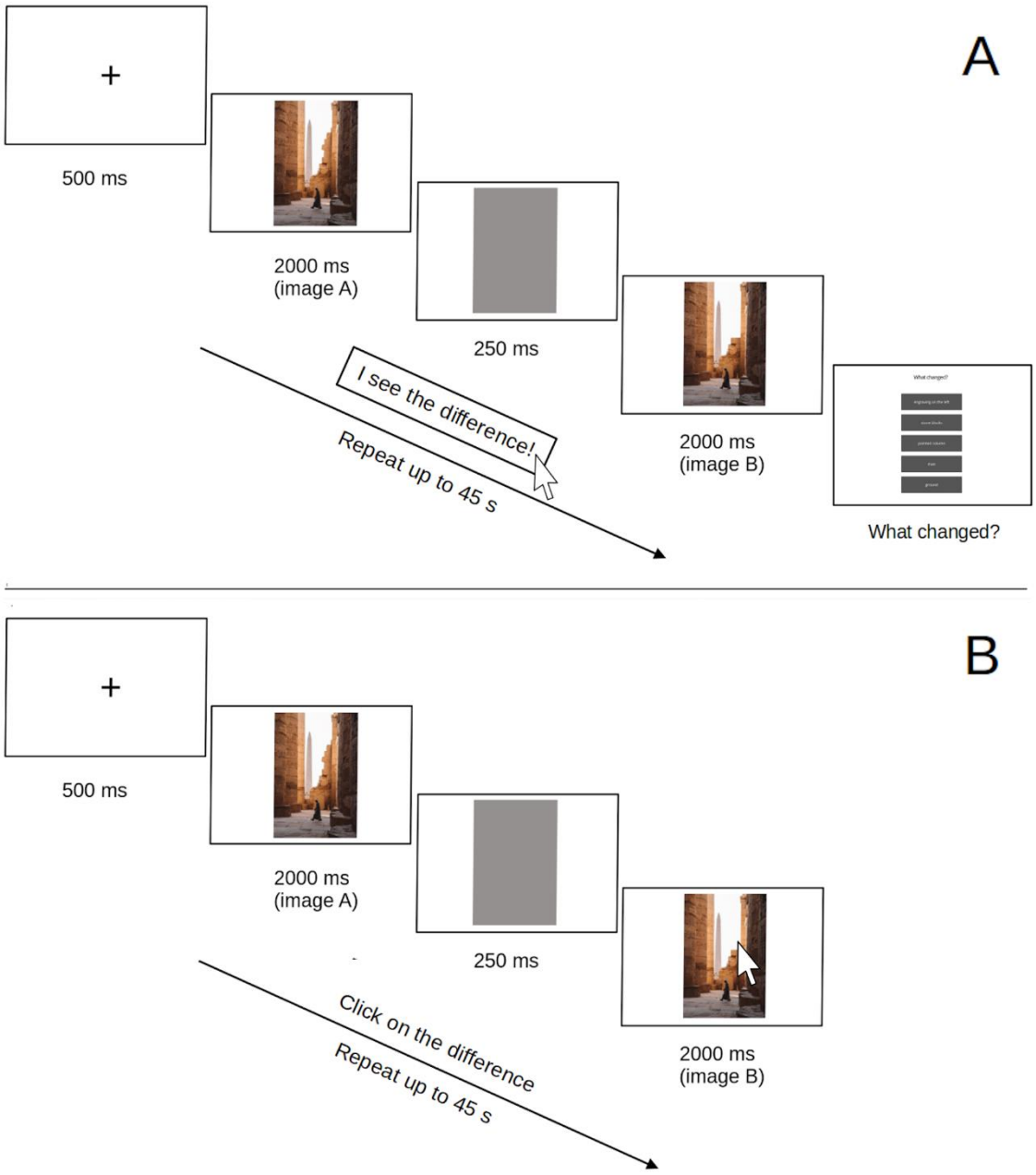

Figure 2.3 Each trial began with a fixation cross shown for 500 ms. Then, a pair of almost identical images (image A and image B), with one distinct change between the two, flickered and off the screen (each image appeared for 2000 ms at a time, with a mask appearing between them for 250 ms). The images flickered for up to 45 s. **A:** In the first study, participants were asked to click on a button once they noticed the difference between image A and image B. After button click, they were instructed to indicate the change by choosing from a 5-item list. **B:** In the replication study, participants were instructed to click with their mouse where the change occurs as soon as they spot the difference between the images.

2.3.4 Metacognition task

This task measures metacognitive efficiency, i.e., the extent to which fluctuation in an individual's objective performance on a perceptual discrimination task corresponds to fluctuation in their subjective confidence in their own accuracy over a series of trials (Fleming, & Lau, 2014). The ability to reflect on and evaluate the accuracy of one's own cognition could contribute to the development of psychological disorders as well as to the outcome of psychological therapies according to cognitive theories of psychological disorders (Beck, 1979; Wells, 2011). Research findings on the association between depression and anxiety symptoms and metacognitive performance are mixed, with some suggesting an impairment in metacognition (Barrientos et al., 2022; Culot et al., 2021; Reyes et al., 2020) and others showing better metacognitive performance (Culot et al., 2021; Rouault et al., 2018).

The task is shown in **Figure 2.4**. In a two-alternative forced choice task, participants were asked to judge which of two boxes contained more dots before rating their confidence in their decision. The task structure was a modified version of that used by (Rollwage et al., 2018). It was programmed in HTML5, CSS2 and JavaScript ES2.

Two 250x250-pixel squares were displayed on the left and right of centre of the screen. The squares were invisibly divided into 625 cells that were randomly filled with dots. On each trial, one randomly chosen square always contained 313 dots and the other contained a greater number of them. Five variations of randomly scattered dot positions were presented for 150 ms each, giving the impression of flickering dots for 750 ms in total. Within one trial, the position of the square with a greater number of dots as well as the number of dots contained in it remained constant.

Practice and calibration phase: Participants first performed 70 practice trials judging whether the left or right square contained more dots (indicated by the left or right arrow keys, respectively). During the practice phase (but not in the main task) feedback was given about the accuracy of participants' judgement after each trial and no confidence rating was elicited. The practice trials were used as a calibration phase to find a stimulus strength (difference between number of dots in each square) that set each participant's performance at ~71% accuracy. This was achieved by a 2-down-1-up staircase procedure (Levitt, 1971) which operated on the logarithm of the difference in number of dots. The difference decreased after two consecutive correct trials at a given stimulus strength and increased after each incorrect trial. The difference changed by .4 natural log number of dots on trials 1-6, by .2 on trials 7-11 and by .1 from trial 12. Participants completed 70 trials of the staircasing procedure and the difficulty of the last 25 trials was averaged to set the individual stimulus strength used in the main task.

Main task: Participants completed two blocks of 45 trials at the stimulus strength determined during the calibration phase. On each trial, they were asked to indicate which of the two squares contained more dots by pressing the left or right arrow keys (feedback about accuracy was no longer given). After each decision, they were instructed to rate their confidence about the accuracy of their decision on a continuous scale (marked as "Guessing" at the lowest point and "Certain" at the highest point). The default value of the scale was set to be in the middle in each trial.

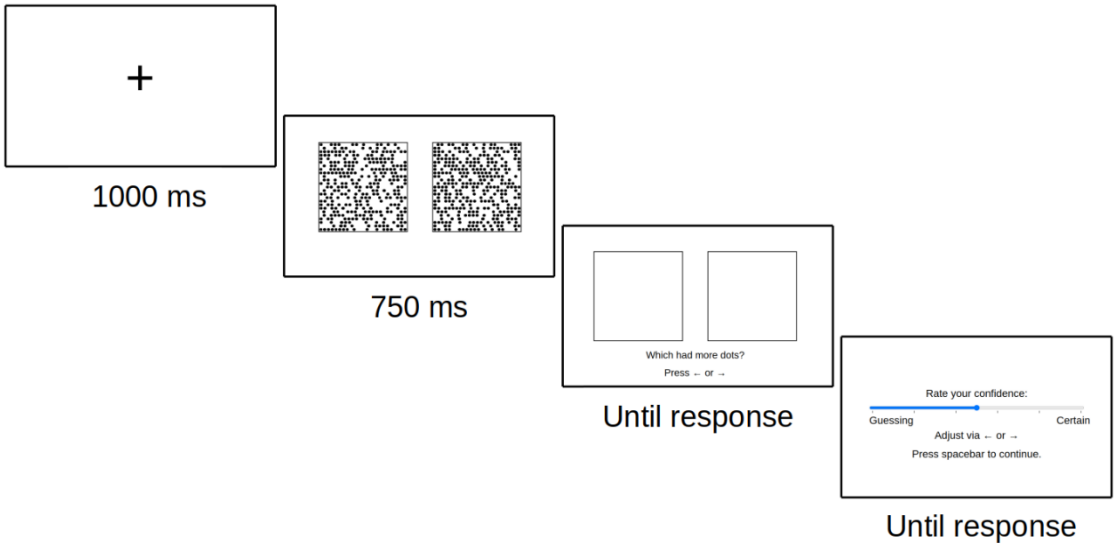

Figure 2.4 Metacognition task. Each trial began with a fixation cross shown for 1000 ms. Then, two squares containing a number of flickering dots appeared on the screen for 750 ms. Following that, the dots disappeared from the squares and participants were asked to indicate which square contained more dots by pressing the left or right arrow keys. After responding with a button press, participants were instructed to rate their confidence in the accuracy of their response by using the left and right arrow keys to adjust a continuous sliding scale ranging from “Guessing” at the lower end and “Certain” at the upper end. Participants then pressed the space bar to move on to the next trial.

Chapter 3: Change blindness, reward bias and negative affective priming: Exploring individual-level associations between depression and anxiety symptoms and cognition

The findings from this chapter have been previously included in the following preprint article: Balogh, A., Lewis, G., Shafran, R., & Robinson, O. J. (2022, October 21). Change blindness, reward bias, negative affective priming: Exploring individual-level associations between depression/anxiety symptoms and cognition. https://doi.org/10.31234/osf.io/vh5pd

3.1 Abstract

Introduction: Cognitive biases are thought to contribute to the development and/or maintenance of mood and anxiety disorders. In addition to self-reported measures, cognitive tasks could potentially be integrated with clinical practice as more precise measures of specific cognitive biases. To further this aim, we conducted a large study to explore the individual-level association between depression/anxiety symptoms as well as clinically relevant metacognitive characteristics and performance on the 1) reward bias task, 2) negative affective priming task and 3) change blindness task.

Methods: N=552 participants, recruited online, performed the tasks alongside self-reported questionnaires measuring depression (Beck Depression Inventory-II) and anxiety symptoms (State-Trait Anxiety Inventory - trait subscale) as well as metacognition (30-item Metacognitive Questionnaire). We used regression analyses to test for associations between task performance and questionnaire scores.

Results: Mean reaction time in in the change blindness task (N=545) was 29 ms quicker for each one-point increase in depression score (B=-27, 95%CI -52 to -2, p=0.034). We found no statistically significant evidence for an association between depression/anxiety scores and reward bias (N=504, BDI-II: B=0.00006, 95% -0.002 to 0.002, p=0.951, STAI-T: B=0.0002, 95%CI -0.001 to 0.002, p=0.804) and negative affective priming (N=539, BDI-II: B=-0.04, 95%CI -1.02 to 0.95, p=0.943, STAI-T: B=-0.06, 95%CI -0.84 to 0.71, p=0.872). Our sample had significantly lower depression (M = 12.3, SD = 9.5) and higher anxiety (M = 47.3, SD = 12.2) symptom scores compared to the sample in a previous online study of the reward bias task (BDI-II: M = 14.9, SD = 11.9, STAI-T: M = 45.3, SD = 12.2) by Daniel-Watanabe et al. (2020) (BDI-II: $t(1492) = 4.3$, $p < 0.001$; STAI-T: $t(1492) = -2.9$, $p = 0.003$).

Conclusions: Our results provide preliminary evidence that individuals with higher self-reported depression scores are *faster* at identifying changes in the change blindness task. This suggests that higher depression symptoms may be associated with a facilitated detection of changes in the environment. Contrary to previous findings, neither reward bias nor negative affective priming effect was associated with depression and anxiety symptoms. However, our sample, recruited entirely during the COVID-19 pandemic, was significantly less depressed and more anxious relative to a previous online study of the reward bias task. This difference may have been caused by the pandemic and could potentially explain why the effects found in previous studies were not replicated in our study. We found no association between metacognition and task performance. In sum, it may be that change-blindness is a useful target cognitive bias in mood and anxiety disorders.

3.2 Introduction

Mood and anxiety disorders have long been thought to be associated with cognitive biases that show preferential processing of negatively valenced information and reduction in positive bias (Alloy & Abramson, 1979; Beck, 1979; Williams et al., 1997; McCabe & Toman, 2000). Cognitive behavioural therapy (CBT) seeks to modify these cognitive biases, which are proposed to be the mechanisms that cause and/or maintain psychopathology (Beck, 1979; Beck et al., 2005). However, only about half of the patients treated with CBT recover (NHS Digital, 2019), and we are not yet able to target CBT to those individuals who are likely to benefit from it.

In recent years, cognitive neuroscience has made many advances in the development of more sensitive measures of cognitive function (Goeleven et al., 2006; Love & Robinson, 2020; Siegel et al., 2018). One of the advantages of this approach is that it provides an objective way of measuring cognition instead of relying on subjective self-reported measures. In addition, cognitive tasks offer a means to delineate the specific mechanisms underlying cognitive biases. Cognitive tasks are yet to be integrated with clinical practice despite their potential benefits of providing personalised treatment and of being used as engaging therapeutic tools.

As a starting point for integrating cognitive tasks with clinical practice, the aim of this study was to collect online data to explore the relationship between a variety of cognitive functions and self-reported depression and anxiety symptoms at the individual level. We collected data from an unscreened general population sample, which has the advantage of increased generalisability, as clinical populations typically consist of individuals seeking treatment who may differ from the general population in important ways. It also allows us to study a greater spectrum of depression and anxiety symptoms,

including at the subclinical level. Furthermore, recruiting participants from the general population leads to gaining more statistical power through larger sample sizes and facilitates future replication of the findings. In addition to these scientific reasons, using an unscreened sample for our study investigating depression and anxiety, which are common in the general population, was sensible in the context of the COVID-19 pandemic, during which normal research processes in this field were disrupted.

As we outline below, all three tasks included are thought to measure processes that have been linked to mood and anxiety disorders and that are targeted by CBT.

3.2.1 Reward bias task

Prior studies suggest that depression and anxiety are associated with a pessimistic tendency, i.e., a reduced anticipation of rewards (Aylward et al., 2019; Love & Robinson, 2020; Pizzagalli et al., 2008). In this task, participants are asked to evaluate whether an ambiguous stimulus is closer to a stimulus resulting in a higher reward or to one resulting in a lower reward. We hypothesized that reduced anticipation of rewards will correlate positively with self-reported depression and anxiety scores.

3.2.2 Negative affective priming task

An impairment in the inhibition of irrelevant negative information may be related to rumination and worry (Williams et al., 1997). The negative affective priming task is used to measure the ability to ignore irrelevant emotional (in this case negative) stimuli (Goeleven et al., 2006). Participants first have to ignore a distractor stimulus and then indicate the valence of a target stimulus. In healthy participants, reaction time is longer when the preceding distractor and the target stimulus match in valence (experimental condition). There is evidence that this effect is reduced in people with depression

(Goeleven et al., 2006). As such, we hypothesized that negative affective priming effect (i.e., reaction time in experimental condition - reaction time in control condition) would correlate negatively with self-reported depression and anxiety scores.

3.2.3 Change blindness task

Change blindness refers to a failure to notice changes in the visual environment (Rensink et al., 1997). Since change blindness paradigms are thought to measure attentional biases towards concern-related cues (Moss et al., 2011), they could potentially be used to reveal attentional mechanisms linked to depression and/or anxiety. In addition, an impairment in noticing changes could be relevant to therapy outcomes. For example, a failure to notice changes in the environment could make learning from behavioural experiments less effective during CBT. To our knowledge, there is currently a lack of evidence as to whether change blindness is associated with depression and anxiety. The change blindness task was developed for the current study and measures the time it takes for participants to notice a change in a scene while it flickers on and off the screen. We had no specific hypothesis about task performance and depression/anxiety symptoms.

3.2.4 Metacognition

In addition to depression and anxiety symptoms, we investigated the association between task performance and self-reported metacognition. A number of metacognitive processes have been identified in the clinical literature as relevant to the development and/or maintenance of depression and anxiety (Wells, 2011). It has also been proposed that psychological therapies exert their effect through metacognition, i.e. the way in which individuals reflect on and evaluate their own thinking (Wells, 2011). Despite its implications for therapy outcomes, research on the association between performance on

cognitive tasks and clinically relevant aspects of metacognition is scarce. Therefore, in this study we attempted to take a step towards discerning the relationship between cognition, metacognition and symptoms of depression and anxiety in an exploratory fashion.

3.2.5 Summary

In summary, in a battery of three online cognitive tasks we explored the relationship between cognitive processes and symptoms of depression and anxiety as well as self-reported metacognition. By examining the link between task performance and symptoms at an individual level, we aimed to identify cognitive tasks that could be integrated into clinical practice as objective measures of cognitive function and/or as therapeutic tools in CBT.

3.3 Methods

3.3.1 Study design

This was a cross-sectional study in which online participants were asked to complete self-reported questionnaires alongside cognitive tasks (the design and hypotheses were preregistered: https://osf.io/v9m2q/).

3.3.2 Participants and recruitment

Participants were recruited online through the Prolific (www.prolific.co) recruitment platform. They were then redirected to Gorilla (www.gorilla.sc), the platform on which the experiment was hosted. Understanding English and access to computer were the only inclusion criteria. 552 participants (308 male, 239 female, 5 other) were recruited and tested. Data was collected between March and July 2020.

3.3.3 Procedure

The study was approved by the University College London Research Ethics Committee (Ethics Project ID number: 15253/001). Participants were provided with an information sheet at the beginning of the study. After an online consent was obtained, participants filled in a demographic questionnaire and the following symptom questionnaires: Beck Depression Inventory-II (BDI-II), State-Trait Anxiety Inventory – trait subscale (STAI-T) and Metacognitive Questionnaire (MCQ-30). Following this, participants completed the negative affective priming, change blindness and reward bias tasks, in this order. Finally, participants completed a bespoke COVID-19 questionnaire which consisted of the following items: ‘How worried are you about the novel coronavirus (COVID-19) outbreak?’ (0-100 scale); ‘How much have you been social distancing?’ (0-100 scale);

‘How would you rate your social distancing experience?’ (1: very good, 2: moderately good, 3: slightly good, 4: slightly bad, 5: moderately bad, 6: very bad, not applicable).

At the end of the study, participants were thanked for their participation, debriefed and provided with a completion code which they used to claim their payment (at a rate of £7.50/hour). The completion of the study took approximately 40 minutes.

3.3.4 Task-by-task exclusion criteria

Participants were excluded from the analysis on a task-by-task basis if there was a strong indication that they did not complete the task according to the instructions.

In the reward bias task (see **Figure 2.1** on page 32), participants were asked to determine whether an ambiguous cue is closer to an extreme cue resulting in a higher reward or to one resulting in a lower reward. Participants with an accuracy of <0.55 on the extreme cue trials were excluded from the analysis as these trials are very easy and poor performance indicates non-adherence to task instructions.

In the case of the negative affective priming task (see **Figure 2.2** on page 35), participants first had to ignore a distractor stimulus and then indicate the emotional valence of a target stimulus across prime and probe trials in experimental and control conditions (**Table 2.1** on page 35). Participants with an accuracy of 0 in either the experimental or the control condition were excluded from the analysis as this did not allow for a negative affective priming effect to be calculated.

In the change blindness task (see **Figure 2.3/A** on page 38), participants were instructed to respond by clicking a button when they spotted the change in an image flickering on and off the screen. They were then asked to choose from a 5-item list where in the image the change occurred. Participants who chose from the list of options with an

accuracy of <0.4 were excluded from the analysis as this suggested that they identified the changes in the images only marginally better than chance, despite indicating to have seen the difference.

3.3.5 Statistical analysis

The sample size of the study was determined based on the effect size obtained for the reward bias task in a previous study (Daniel-Watanabe et al., 2022). To achieve 90% power (at alpha=0.05, r=-.13, one-tailed test), we stopped recruiting once 504 eligible participants completed the reward bias task. Participants were recruited in batches, and interim analyses were conducted on the reward bias task after every 126 eligible participants. We used the stopping rule of the O'Brien-Fleming approach (O'Brien & Fleming, 1979). For an overall significance level of alpha=0.05, the study was to be stopped at an obtained alpha value below 0.00005, 0.0039, 0.0184, 0.0412 for the four consecutive interim analyses. The total number of participants was capped at 4x126=504.

All analyses were performed in Python 3.6.9.

For the reward bias task, bias was measured by the proportion of high reward responses to intermediate stimuli p(mid-as-high). For the negative affective priming task, the dependent variable was the 'negative affective priming effect' (i.e., reaction time in experimental condition - reaction time in control condition). For the change blindness task, we used mean reaction time on correct trials as the dependent variable.

To assess the internal consistency of our cognitive measures, we determined the split-half reliability of each task (100,000 random splits using scipy1.5.2 package). This number puts an upper bound on the potential correlation between a task and another

variable. For the reward bias task, split-half reliability of responses to the intermediate trials was measured. In the case of the negative affective priming task, we determined split-half reliability of reaction times in the experimental condition as well as in the control condition, separately. For the change blindness task, split-half reliability of reaction times on correct trials was measured.

For each cognitive task, simple linear regressions (one regression per questionnaire per task) were conducted using the statsmodels v.0.11.1 package to test which questionnaire scores are significantly associated with task performance. We then performed multivariate regression analyses for each task, including all predictor and control variables.

To further establish the robustness of the association between mean reaction time in the change blindness task and self-reported depression score, we conducted a permutation analysis. We determined an empirical null distribution of Pearson's r correlation between mean reaction time and BDI-II scores by randomly permuting mean reaction time over 100,000 iterations. We then calculated the p-value of the correlation observed in our original sample**.**

Comparison with prior sample:

Since we used the same reward bias task as (Daniel-Watanabe et al., 2022), we performed two independent samples t-tests on BDI-II and STAI-T scores to determine if our study sample was significantly different from theirs with regard to depression and anxiety. This is particularly important since, unlike this prior study, our data collection occurred during the early stages of the COVID-19 pandemic.

3.4 Results

Out of 552 participants, 1 (0.2%) has a diagnosis of schizophrenia, 9 (1.6%) reported a diagnosis of bipolar disorder, 17 (3%) have a neurological disorder and 41 (7.4%) have been diagnosed with a learning disability.

3.4.1 Reward bias task

The final sample had N=504 participants (after excluding N=48, 9%) with mean BDI-II score=12.3 (SD=9.5) and mean STAI-T score=47.3 (SD=12.2). Responses were significantly biased toward highest reward (test≠0.5, t(503)=17, p<0.001, 95%CI=0.63-0.67) (**Figure 3.1/A**). The Spearman-Brown corrected split-half reliability of intermediate trials was r_{SB} = 0.96. As shown in **Table 3.1**., we found no evidence of association between p(mid-as-high) and self-reported depression/anxiety scores (BDI-II: B=0.00006, 95%CI -0.002 to 0.002, p=0.951, STAI-T: B=0.0002, 95%CI -0.001 to 0.002, p=0.804). When adjusting for gender, we found evidence for reduced positive bias in females (B=-0.04, 95%CI -0.07 to -0.001, p=0.046).

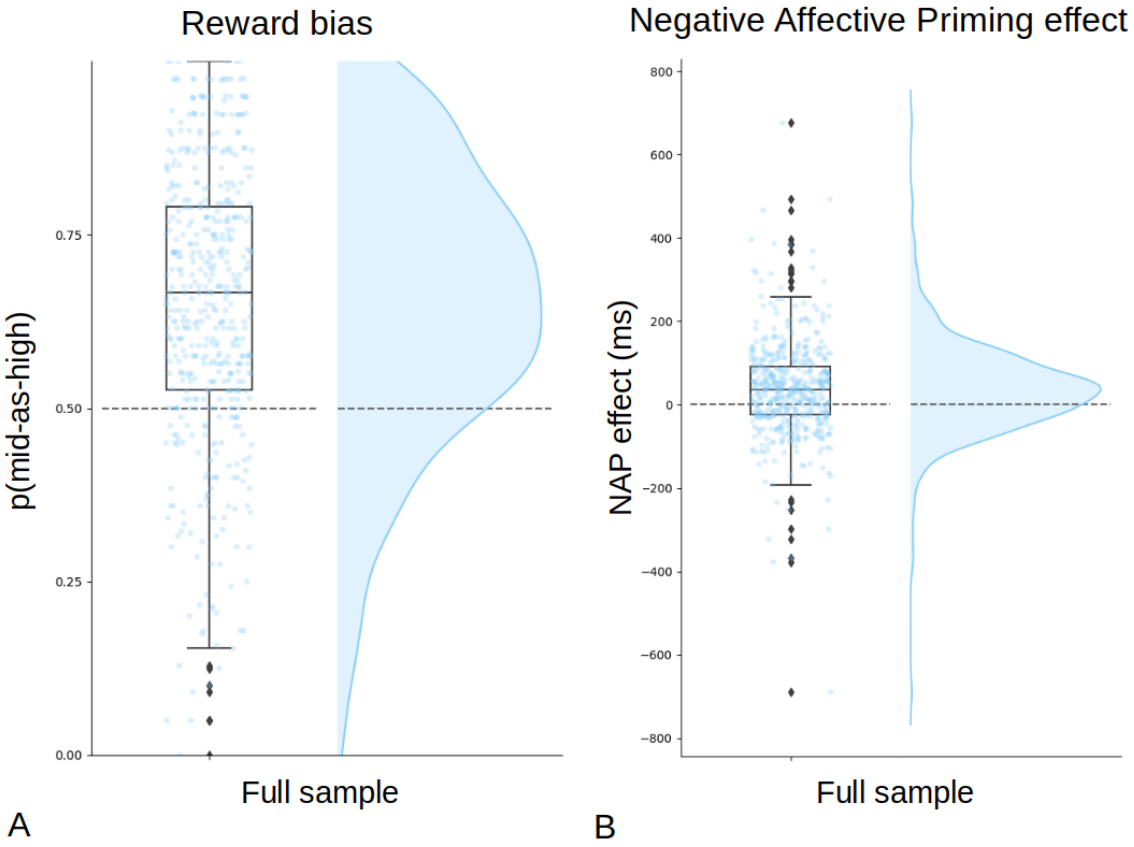

Figure 3.1 Reward bias and negative affective priming effect. **A:** Reward bias in the full sample, measured by the proportion of high reward responses to intermediate stimuli. **B:** Negative affective priming effect in the full sample, measured by reaction time in experimental condition – reaction time in control condition.

p(mid-as-high)			
Unadjusted			
	B	**CI**	**p**
BDI-II	0.00006	-0.002 to 0.002	0.951
STAI-T	0.0002	-0.001 to 0.002	0.804
Adjusted			
BDI-II	-0.0004	-0.004 to 0.003	0.800
STAI-T	0.0008	-0.002 to 0.003	0.519
Age	0.002	-0.001 to 0.004	0.152
Gender	-0.04	-0.07 to -0.001	0.046*

Table 3.1 Reward bias task regression analyses: Unadjusted and adjusted linear regression coefficients (B) with confidence intervals (CI) and p-values (p).

3.4.2 Comparison of samples from current study and previous reward bias study

Given our failure to replicate the relationship between reward bias and depression symptoms (**Figure 3.3**), we compared BDI-II scores in our sample which was collected during the global pandemic (M = 12.3, SD = 9.5) with BDI-II scores in the Daniel-Watanabe et al. (2020) N=990 sample (M = 14.9, SD = 11.9), shown in **Figure 3.2**. Participants in the current study scored significantly lower on depression symptoms, $t(1492) = 4.3$, $p < 0.001$. In contrast, when comparing STAI-T scores in our sample (M = 47.3, SD = 12.2) and in the Daniel-Watanabe et al. sample (M = 45.3, SD = 12.2), we found that participants in the current study reported significantly higher levels of anxiety symptoms, $t(1492) = -2.9$, $p = 0.003$.

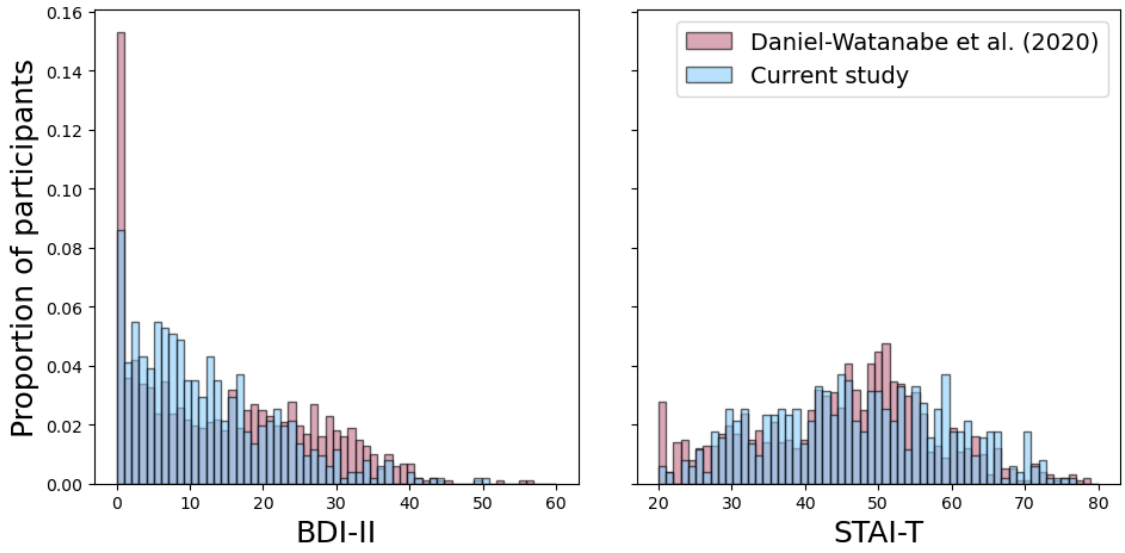

Figure 3.2 Sample characteristics of reward bias studies. Distribution of BDI-II and STAI-T scores in the current study sample (blue) and the Daniel-Watanabe et al. (2020) study sample (red).

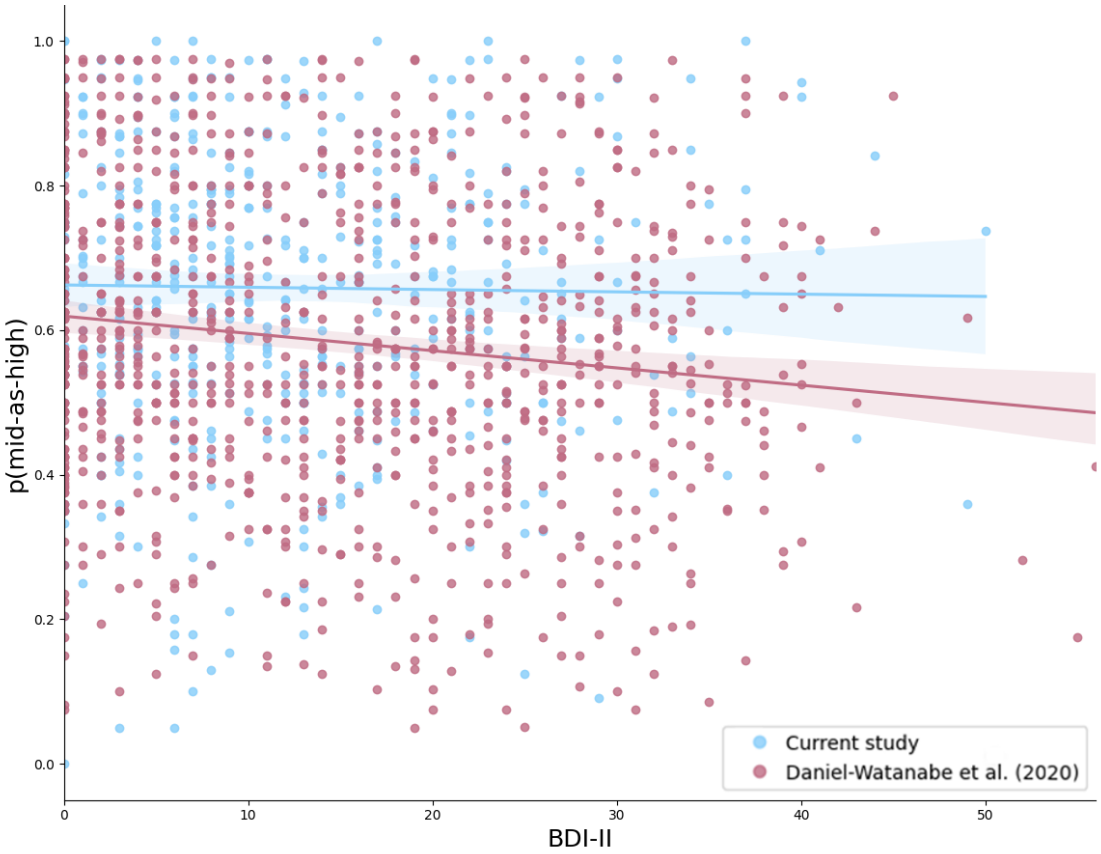

Figure 3.3. Reward bias across study samples. Correlation between BDI-II scores and reward bias in the current study sample (red) and the Daniel-Watanabe et al. (2020) sample (blue), showing 95% confidence intervals.

3.4.3 Negative affective priming task

The final sample (N=539, after excluding N=13, 2%) had a mean BDI-II score=12.4 (SD=9.6) and a mean STAI-T score=47.2 (SD=12.2). We found a significant negative affective priming effect (test≠0, t(538)=8, p<0.001, 95%CI=28.24-47.18) (**Figure 3.1/B**). The split-half reliability of mean reaction times was r_{SB} = 0.80 in the experimental condition and r_{SB} = 0.78 in the control condition. As shown in **Table 3.2**, there was no evidence of association between negative affective priming effect and self-reported depression/anxiety scores (BDI-II: B=-0.04, 95%CI -1.02 to 0.99, p=0.943, STAI-T: B=-0.06, 95%CI -0.84 to 0.71, p=0.872).

Negative affective priming effect			
Unadjusted			
	B	**CI**	**p**
BDI-II	-0.04	-1.02 to 0.99	0.943
STAI-T	-0.06	-0.84 to 0.71	0.872
Adjusted			
BDI-II	0.1	-1.6 to 1.9	0.893
STAI-T	-0.2	-1.6 to 1.2	0.763
Age	-0.1	-2.2 to 0.2	0.110
Gender	-15	-34 to 3	0.111

Table 3.2 Negative affective priming task regression analyses: Unadjusted and adjusted linear regression coefficients (B) with confidence intervals (CI) and p-values (p)

3.4.4 Change blindness task

The final sample included 545 participants (N=7, 1%, excluded) with mean BDI-II score=12.4 (SD=9.5) and mean STAI-T score=47.2 (SD=9.6). The split-half reliability of reaction times on correct trials was r_{SB} = 0.30. In the unadjusted linear regression analysis, mean reaction time in in the change blindness task was significantly associated with self-reported depression scores (B=-27, 95%CI -52 to -2, p=0.034; **Table 3.3, Figure 3.4**). Individuals who scored higher on symptoms of depression were *faster* at identifying changes in the images. This effect was larger but not statistically significant (B=-30, 95% CI -74 to 14, p=0.179) after adjusting for anxiety, age and gender. In our permutation analysis, we found a significant Pearson's r correlation between mean reaction time and BDI-II scores (p=0.034).

There was no evidence for an association between mean reaction time in the change blindness task and self-reported anxiety scores (B=-17, 95% CI -37 to 3, p=0.092). We found that older participants had a significantly higher reaction time (B=38, 95%CI 8 to 68, p=0.014).

We looked at reaction times across the two other tasks. We found no association between anxiety/depression scores and mean reaction time in either the reward bias task (BDI-II: B=-0.6, 95%CI -1.6 to 0.4, p=0.235; STAI-T: B=-0.3, 95%CI -1.1 to 0.5, p=0.425) or the negative affective priming task (BDI-II: B=-0.7, 95%CI -2.6 to 1.2, p=0.452; STAI-T: B=-0.3, 95%CI -1.8 to 1.2, p=0.681) indicating that there was not a generic effect of depression on reaction time.

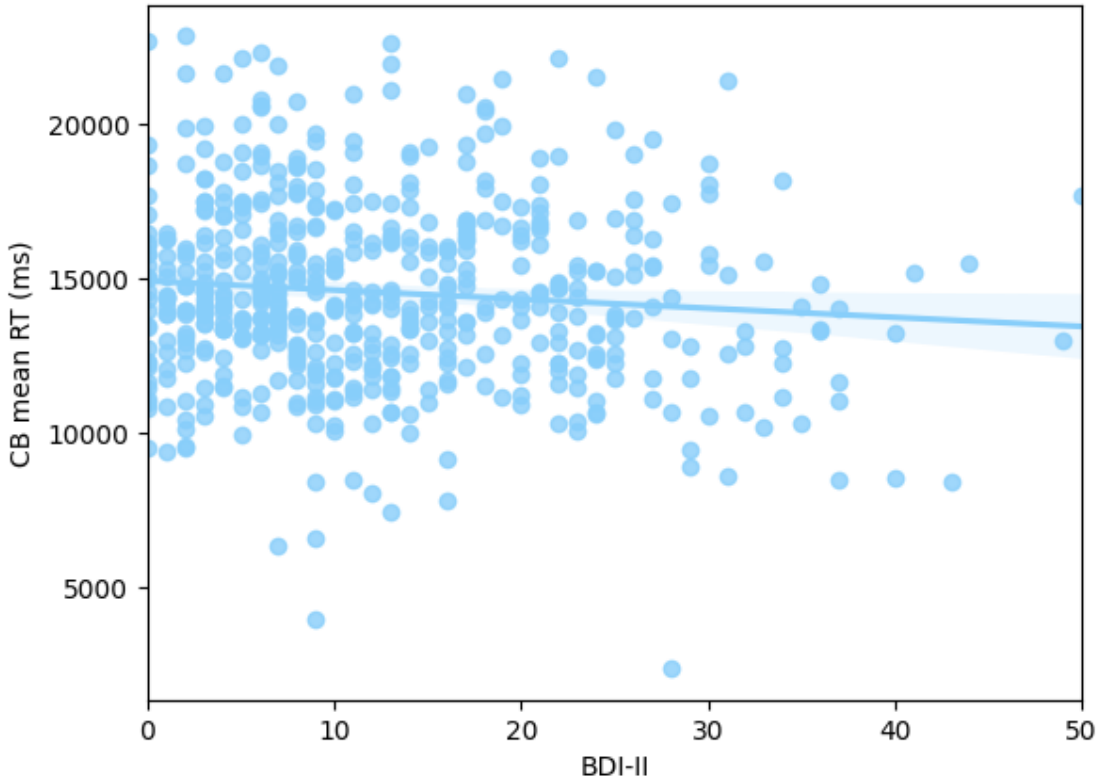

Figure 3.4 Association between change blindness task performance and depression symptoms: Mean RT~BDI-II regression (B=-27, 95%CI -52 to -2, p=0.034).

Mean reaction (ms) time in change blindness task			
Unadjusted			
	B	**CI**	**p**
BDI-II	-27	-52 to -2	0.034*
STAI-T	-17	-37 to 3	0.092
Adjusted			
BDI-II	-30	-74 to 14	0.179
STAI-T	8	-27 to 43	0.643
Age	38	8 to 68	0.014*
Gender	-76	-546 to 395	0.752

Table 3.3 Change blindness task regression analyses: Unadjusted and adjusted linear regression coefficients (B) with confidence intervals (CI) and p-values (p)

3.4.5 Exploratory analyses

Correlations between questionnaires:

Correlations between questionnaires are shown in **Figure 3.5**. Depression and anxiety scores were the most highly related (r=0.82). MCQ-30 total scores were also highly correlated with depression (r=0.55) and anxiety (r=0.59). In addition, there was a strong association between negative beliefs about the danger and uncontrollability of worry and depression (r=0.67) and anxiety (r=0.75).

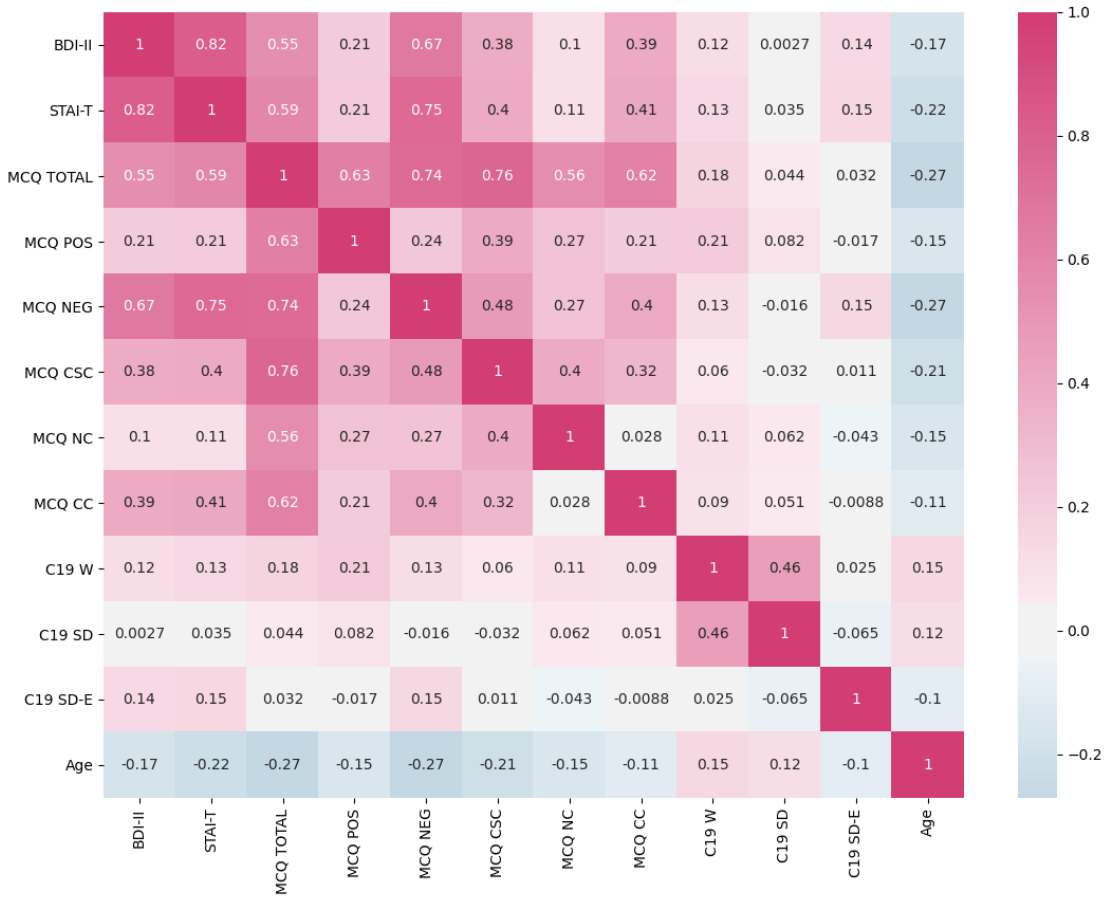

Figure 3.5 Heatmap of correlations between questionnaires and age. BDI-II = Beck Depression Inventory-II; STAI-T = State-Trait Anxiety Inventory – Trait subscale; MCQ Total = Metacognitions Questionnaire (MCQ) – Total scores; MCQ POS =MCQ 'Positive beliefs about worry' subscale; MCQ NEG = MCQ 'Negative beliefs about uncontrollability and danger of worry' subscale; MCQ CSC = MCQ ' Cognitive self-consciousness' subscale; MCQ NC = MCQ 'Need to control thoughts' subscale; MCQ CC = MCQ 'Cognitive confidence' subscale; C19 W = COVID-19 worry; C19 SD = COVID-19 social distancing; C19 SD-E = COVID-19 social distancing experience

Exploratory analyses including covariates:

For each cognitive task, we performed multiple linear regression analyses, including all predictor variables as well as covariates of no interest – age, gender, worry about COVID-19, self-reported amount of social-distancing, subjective experience of social distancing (from very good to very bad). Depression and anxiety symptoms remained not significantly associated with either reward bias or negative affective priming effect

and the depression effect in change-blindness was replaced by a larger effect of age (**Table 3.4**).

Predictor/control variables	Dependent variables					
	p(mid-as-high) in reward bias task		Negative affective priming effect		Mean reaction time in change blindness task	
	B	p	B	p	B	p
BDI-II	-0.0003	0.853	-0.2	0.856	-33	0.157
STAI-T	0.002	0.273	-0.8	0.359	3	0.867
MCQ total	-0.001	0.126	0.7	0.092	-4	0.654
MCQ positive beliefs about worry	-0.003	0.307	-0.8	0.525	-51	0.121
MCQ negative beliefs about uncontrollability and danger	0.0006	0.833	2	0.328	25	0.554
MCQ cognitive self-consciousness	0.003	0.298	-0.5	0.772	8	0.861
MCQ need to control thoughts	0.001	0.674	0.49	0.737	-6	0.875
MCQ lack of cognitive confidence	-0.004	0.080	-0.1	0.901	20	0.491
COVID-19 worry	<0.001	0.891	-0.1	0.539	7	0.205
COVID-19 level of social distancing	<0.001	0.963	0.2	0.296	-2	0.675
COVID-19 social distancing experience (from very good to very bad)	0.003	0.666	1	0.784	118	0.207
Age	0.002	0.145	-0.7	0.316	38	0.020*
Gender	0.003	0.060	-17	0.097	-109	0.670

Table 3.4 Exploratory regression analyses including covariates for each task: Multivariate linear regression coefficients (B) and p-values.

Impact of COVID-19 on mood symptoms:

We found that worry about the COVID-19 pandemic and experience of social distancing (from very good to very bad) were significantly associated with both BDI-II and STAI-T scores (**Table 3.5**). Individuals with increased depression and anxiety symptoms worried more about COVID-19 and reported a worse experience of social distancing (on

a scale from ‘very good’ to ‘very bad’). We found no association between self-reported amount of social distancing and depression/anxiety.

BDI-II		
	B	**p**
Worry about COVID-19 outbreak	0.33	0.007**
Level of social distancing	0.007	0.950
Experience of social distancing (from very good to very bad)	0.02	0.002**
STAI-T		
Worry about COVID-19 outbreak	0.31	0.002**
Level of social distancing	0.07	0.425
Experience of social distancing (from very good to very bad)	0.02	<0.001***

Table 3.5 Association between COVID-19 questionnaire items and symptom measures: Simple linear regression weights and p-values with COVID-19 questionnaire items as predictor variables for Beck Depression Inventory-II and State-Trait Anxiety Inventory – trait subscale.

3.5 Discussion

We provide preliminary evidence that individuals with higher self-reported depression scores are *faster* at identifying changes in images in the change blindness task. However, counter to our predictions, there was no evidence of the predicted association between cognitive task performance and depression/anxiety scores in the reward bias and negative affective priming tasks.

Participants with higher levels of depressive symptoms were faster at spotting changes in images, suggesting that depression may be associated with a facilitated detection of changes in the environment. We found no statistically significant evidence for this association after controlling for anxiety, age and gender although it is worth noting that the size of the effect increased in the adjusted analysis. Therefore, it is possible that we lacked statistical power to detect an association when controlling for confounding variables. Furthermore, there was no relationship between depression scores and reaction time in the same sample across the other two tasks of the study. As such, we have no evidence that the reaction time effect observed in the change blindness task is related to general psychomotor characteristics.

All stimuli in the change blindness task included humans with changes happening only in their surroundings. One possible explanation of our findings could be that individuals with higher depression scores pay decreased attention to social information and are thus quicker at noticing changes in surroundings. In contrast, those with lower depression scores may pay preferential attention to social stimuli. This would be consistent with previous findings about the association between depression and social anhedonia, which is characterised by a reduced drive for social relationships and belonging as well as decreased social functioning (Kupferberg et al., 2016).

Another possible explanation of our results could be that people with more severe depressive symptoms are more likely to scan the environment for potential threats. This could be due to the high correlation between depression and anxiety disorders although we did not find a significant association between anxiety symptoms and task performance in this study. It is also conceivable that increased depressive symptoms are associated with weaker predictions about the state of the world and/or a greater weight put on prediction error signals, which would result in decreased change blindness.

It is possible that the change blindness task could be integrated with clinical practice as a measure of attentional bias. Individual performance on the task could potentially inform CBT treatment in various ways. For example, decreased attention to social information would suggest the use of social activity scheduling, whereas increased attention to threat would point to conducting specific behavioural experiments. In addition, an increased attention to threat indicated by the change blindness task could possibly suggest that an individual is likely to benefit from CBT augmented by attention bias modification, a promising new computerised treatment for anxiety disorders, which uses cognitive tasks to train patients to direct their attention away from threats (Kuckertz, & Amir, 2017). Furthermore, future research could explore whether the change blindness task could be usefully introduced as part of attentional bias modification, as an addition to the currently used dot-probe and visual search tasks (Kuckertz, & Amir, 2017). It is possible, for example, that attention bias modification using a combination of different tasks has a higher level of generalisability to real-world situations.

Future studies should aim to replicate and narrow down the mechanisms underlying the association between change blindness task performance and depression by manipulating

the content of the images and the features that change. The effect could also be studied using moving, instead of static, images. One advantage of this approach would be that the stimuli shown could closely mimic real-life situations and thus potentially be more relevant to clinical practice.

We explored a supplemental analysis of the effect of depression on mean reaction time in the change blindness task looking at age-matched groups at clinical extremes (BDI-II score <13 in the healthy group and BDI-II score 29< in the severely depressed group). However, after completing nearest neighbour propensity score analysis to match the groups using the MatchIt R package, the two groups were still unacceptably imbalanced for age, indicating that age and depression scores are confounded. Future studies are needed to discern the relationship between age, depression and change blindness by recruiting age-matched groups.

Of note, we failed to replicate the previous finding that reward bias is associated with self-reported depression scores (Daniel-Watanabe et al., 2022). We also found no evidence for an association between negative affective priming effect and self-reported depression (reported by Goeleven et al., 2006) and anxiety score. These tasks were included in our study because they are thought to measure 1) reward deficits and 2) the inability to supress negative information as a proxy for rumination and worry, both of which are constructs that have been linked to depression and anxiety (Michl et al., 2013; Russo & Nestler, 2013). If our null results are true, it is possible that our tasks failed to measure these mechanisms. In both cases, these tasks had good split-half reliability, so these null results cannot be easily assigned to measurement error. It could also be the case that reward bias, rumination and worry encompass multiple mechanisms, only some of which are related to depression and anxiety. Another explanation for our null

results could be the different context in which the reward bias and negative affective priming tasks were delivered in our study relative to previous studies. Specifically, the tasks were administered as part of an approximately 40-minute-long experiment, including three cognitive tasks preceded four questionnaires. Participants' exhaustion and/or boredom could have affected their cognitive performance, as suggested by previous research (Tyng et al., 2017). Alternatively, it is possible that previous associations were false positives, especially given that the average statistical power in neuroscientific studies is low, which also reduces the chance that a statistically significant result reflects a true effect (Button al., 2013).

However, it is important to note that exploratory analyses revealed significant differences between the symptoms reported by this current sample and the previous online reward bias sample (Daniel-Watanabe et al., 2022), which could have contributed to the null results. These differences might be driven by the COVID-19 pandemic (Deoni et al., 2022) – indeed we saw relationships between mood symptoms and experience of the pandemic, see **Table 3.5**. Sample differences could also be due to the use of different online recruitment platforms – Mturk vs. Prolific (Daniel-Watanabe et al., 2022), or even due to other demographic characteristics (the Mturk platform has a more global reach). Given that both depression and anxiety are heterogeneous constructs comprising of a cluster of symptoms, sample differences could have led to different results if 1) differences in depression and anxiety across samples are driven by specific symptoms and 2) the reward bias and negative affective priming tasks measure cognitive processes related to specific symptoms. In the case of the negative affective priming task, there is evidence from previous research (Goeleven et al., 2006) that a reduced negative affective priming effect is related to a tendency to ruminate/worry. It is conceivable that our sample was different from previous samples on this specific

symptom. For example, the heightened anxiety observed in our sample recruited during the COVID-19 pandemic could have been driven by more individuals feeling physically tense and struggling to sleep, without also having developed tendencies to worry and ruminate. Similarly, the conflicting findings observed in the reward bias task could also be due to sample differences in specific symptoms of depression and anxiety. To the best of our knowledge, no previous study, other than the one cited (Daniel-Watanabe et al., 2022) has used this exact version of the paradigm in humans, and future research is needed to disambiguate the relationship between task performance and specific depression and anxiety symptoms. In summary, it cannot be ruled out that different sample biases led to the conflicting results on the reward bias and negative affective priming tasks.

We also found no evidence for an association between metacognition and task performance. Nevertheless, it is possible that metacognitive strategies, i.e., the strategies individual participants chose to complete the tasks, may have affected task performance in addition to lower order cognitive processes, such as attention. In particular, in the case of the change blindness task, mean reaction time could have been influenced by participants' confidence in their own perception and whether or not they chose to "double-check" if they correctly identified the changes in the images before responding. Future studies should investigate this further by asking participants about the strategy used while completing the task. This is especially important given the low to moderate correlations we found between metacognitive processes and symptoms of depression and anxiety.

3.5.1 Strengths and Limitations

Although understanding English and access to computer were the only inclusion criteria, our online sample of Prolific users is unlikely to be representative of the general UK population, which might affect the generalisability of the findings. However, since our participants were recruited in the same way from the same pool, our comparisons across tasks are not affected by selection bias as we were making comparisons within our sample.

Although we collected data on co-morbid schizophrenia, bipolar disorder, learning disability and neurological disorder diagnoses (present in 0.2 to 7.4% of participants), these variables were not included in our analyses, which could have biased our results. Importantly, our study does not include data on depression and anxiety disorder diagnoses. Therefore, we cannot draw strong conclusions about whether our findings based on self-reported depression and trait anxiety scores generalise to clinical presentations of depression and anxiety disorders.

Even though we excluded participants on a task-by-task basis if we had a strong indication that they did not complete the task according to the instructions (1-9% of participants), our study did not include 1) "catch" questions and trials to test attention, and 2) questions about whether the participant understood the instructions. We also only excluded implausibly fast reaction times from the negative affective priming task. It is worth noting, however, that the fact that we found statistically significant population-level reward bias and negative affective priming effects consistent with previous studies strongly suggests that, overall, participants complied with the instructions and completed the tasks adequately.

It is also possible that our study was underpowered. The effects of depression and anxiety in the negative affective priming task were in the predicted direction, although small. However, it is worth noting that this was not the case in the reward bias task where the effects of depression and anxiety were very close to zero and in the opposite direction of what we predicted. Furthermore, the 95% confidence interval in the reward bias task was narrow enough not to overlap with the confidence interval found in the same task by (Daniel-Watanabe et al., 2022).

The change blindness task had low split-half reliability. However, this measure is likely to be less meaningful in this task because identifying the change is more difficult in certain images than in others. Nevertheless, low split-half reliability could be contributing to measurement error and a lack of statistical power to detect relationships with individual differences in task performance.

In addition, the COVID-19 pandemic and lockdown may have affected our results, particularly if the unusual circumstances had an impact on participants' mood and anxiety level. We found that participants in the current study were significantly less depressed and more anxious than participants who completed the same reward bias task in a study by (Daniel-Watanabe et al., 2022). Our exploratory analysis did not suggest a significant association between task performance and worry about the pandemic, level of social distancing or experience of social distancing (**Table 3.4**), but we did identify relationships between depression and anxiety and these factors (**Table 3.5**) so the impact of this on our findings cannot be ruled out.

Furthermore, in the case of the reward bias task, we may have failed to find a true effect due to the design of our study: Participants completed this task last, and fatigue/lack of concentration could have influenced the results. Future work may seek to

counterbalance task order to avoid these effects. In addition to this, our analysis of the reward bias task did not include potential block effects, which could have led to a false negative finding. A previous study has found that individuals with a sub-clinical level of depressive symptoms are indistinguishable from healthy controls during the initial blocks of the task but show a marked reduction in reward bias towards the end of the task (Liu et al., 2015). In contrast, individuals with high depression scores showed a reduced reward bias throughout the task. Especially in light of our finding that our sample was significantly less depressed than a previous online sample completing an identical version of the reward bias task (Daniel-Watanabe et al., 2022), it is possible that an analysis of the later blocks of the task would show an effect of depression on reward bias.

Finally, due to the length of the experiment, our study did not include measurements of potential confounding variables, such as IQ or working memory. Also, since our findings are cross-sectional it is not possible to infer the causal direction of the associations found.

3.5.2 Summary

Cognitive tasks may be useful tools in clinical practice as objective measures of cognitive biases in depression and anxiety. However, in order to integrate cognitive testing with clinical practice it is necessary that these measures are validated for individual differences. We conducted a large online study to explore the association between task performance and depression/anxiety symptoms at the individual level. We found preliminary evidence that people with higher levels of depression are *faster* at identifying changes in images in the change blindness task. Contrary to previous findings, neither reward bias nor negative affective priming effect was associated with

depression/anxiety. Future studies should seek to replicate the change blindness effect, explore its underlying mechanisms, and better understand which cognitive functions these three tasks measure.

Chapter 4: Change blindness in depression and anxiety

As in Chapter 3, the findings from this chapter have been included in the following preprint article: Balogh, A., Lewis, G., Shafran, R., & Robinson, O. J. (2022, October 21). Change blindness, reward bias, negative affective priming: Exploring individual-level associations between depression/anxiety symptoms and cognition. https://doi.org/10.31234/osf.io/vh5pd

4.1 Abstract

Introduction: Cognitive biases, including attentional biases, are thought to characterise mood and anxiety disorders. In addition to self-reported measures, cognitive tasks could potentially be applied in clinical practice as more precise and objective measures of specific cognitive biases. Change blindness paradigms are thought to measure attentional biases towards concern-related cues. Therefore, they could potentially be used to reveal attentional mechanisms linked to depression/anxiety. To further this aim, we conducted a large replication study to explore the individual-level association between depression/anxiety symptoms and performance on a change blindness task.

Methods: N=616 participants, recruited online, performed the change blindness task alongside self-reported questionnaires measuring depression (Beck Depression Inventory-II) and anxiety symptoms (State-Trait Anxiety Inventory - trait subscale) as well as metacognition (30-item Metacognitive Questionnaire). We used regression analyses to test for associations between task performance and questionnaire scores. We then performed a mega-analysis (N=1161) by pooling raw data across the current change blindness study and the study in Chapter 3.

Results: In the change blindness replication study, mean reaction time was 16 ms quicker for each one-point increase in depression score (B=-15, 95%CI -∞ to -15, p=0.045) and 16 ms quicker for each one-point increase in anxiety score (B=-17, 95%CI -31 to -2, p=0.022). In the mega-analysis, we found a significant association between mean reaction time and depression symptoms (B=-20, 95%CI -35 to -5, p=0.007) as well as anxiety symptoms (B=-17, 95%CI -28 to -5, p=0.006). These effects were not significant after adjusting for age (correlation with age was r=-0.1 for depression and r=-0.12 for anxiety).

Conclusions: Our results provide preliminary evidence that individuals with higher self-reported depression and anxiety scores are *faster* at identifying changes in the change blindness task. This suggests that higher depression symptoms may facilitate the detection of changes in the environment although this effect may be at least partially driven by age.

4.2 Introduction

Previous research suggests that depression and anxiety are characterised by cognitive biases and impairments (Alloy & Abramson, 1979; Beck, 1979; Beck et al., 2005; McCabe & Toman, 2000). These include biases and impairments in attention (Bar-Haim et al., 2007; Eysenck et al., 2007; Rock et al., 2014).

As proposed in the previous chapter, cognitive tasks can be used as objective measures of these cognitive processes and their underlying mechanisms but are not yet integrated with clinical practice despite their potential to 1) inform which individual is likely to benefit from CBT, 2) personalise CBT, and 3) be used as demonstration tools in therapy so that patients gain insight into their own cognitive biases. In the previous chapter we tested the impact of anxiety and depression symptoms on three cognitive processes, but only found evidence for an effect on one: change blindness. In this chapter we sought to replicate this effect to increase our confidence in its robustness.

Change blindness is a phenomenon that occurs when an observer fails to notice a visual change that is easily seen once pointed out. In change blindness paradigms, these changes happen after brief disruptions, such as distractors, blank intervals, or eye movements (Rensink et al., 1997). Change blindness paradigms are thought to measure attentional biases towards concern-related cues (Moss et al., 2011). It has been shown that changes are spotted faster if they are 1) attended to (based on eye-tracking), 2) relevant to behaviour, 3) surprising, and 4) have social significance (Smith & Milne, 2009). These processes can all be considered relevant to the attentional biases found in depression and anxiety (Eysenck et al., 2007; Rock et al., 2014).

Previous research has found reliable individual differences in the ability to notice changes in the visual environment (Andermane et al., 2019). However, there is currently

a paucity of research on change blindness in depression and anxiety despite its potential to reveal more about specific mechanisms underlying attentional biases and impairments in these conditions. Our initial results from a large online study (Chapter 3) suggest that individuals with higher self-reported depression scores may be *faster* at identifying changes in images using a change blindness paradigm. We proposed that depression may be associated with a facilitated detection of changes in the environment, possibly due to hypervigilance (i.e., a heightened tendency to scan the environment for potential threats) or weaker predictions about the state of the world and/or a greater weight put on prediction error signals

Of note, all images in our previous study had social content (i.e., included humans) and all changes occurred in the *surroundings* of humans. Therefore, it is unclear whether the effect we found is general or, instead, specific to the content of the images. A decreased attention to humans, and thus faster noticing of changes in the environment, may be explained by social anhedonia observed in depression (Kupferberg et al., 2016). An alternative explanation could be that individuals with higher depression scores are more likely to scan the environment for threats due to the high correlation between depression and anxiety.

The purpose of the current study was to replicate and further investigate the individual-level association between performance on the change blindness task and depression/anxiety symptoms in a large online study. To explore whether the effect was content-specific or general, we included three conditions in which changes occurred in 1) the surroundings of humans (as in our original study), 2) humans, and 3) non-social scenes.

We hypothesised that individuals with higher self-reported depression scores will be faster at spotting the difference in the images, and explored whether this was modulated by the social content of the images.

As discussed in the previous chapters, several metacognitive processes (i.e., the way in which people reflect on and evaluate their own thinking) have been identified as characteristic of depression and anxiety (Rouault et al., 2018; Wells, 2011). Furthermore, metacognition could be a crucial underlying mechanism of psychological therapies (Wells, 2000). Therefore, in this study we conducted further exploratory analyses on the relationship between performance on the change blindness task, depression and anxiety symptoms and self-reported metacognition.

4.3 Methods

4.3.1 Study design

This was a cross-sectional study in which online participants were asked to complete self-reported questionnaires alongside cognitive tasks (the design and hypothesis were preregistered: https://osf.io/s86v9/).

4.3.2 Participants and recruitment

Participants were recruited online through the Gorilla (www.gorilla.sc) and Prolific (www.prolific.co) platforms between June and September 2021. Understanding English and access to computer were the only inclusion criteria. 616 participants were recruited and tested.

4.3.3 Procedure

The study was approved by the University College London Research Ethics Committee (Ethics Project ID number: 15253/001). Participants were provided with an information sheet at the beginning of the study. After an online consent was obtained, participants filled in demographic and symptom questionnaires. (Unlike in our previous study described in Chapter 3, we did not administer a COVID-19-related questionnaire.) Following this, participants completed the change blindness task in which they were instructed to notice a single change in a series of images as they flickered on and off the screen (see **Figure 2.3/B** on page 38). As a slight modification to the change blindness task in our previous study (Chapter 3), participants in this study clicked on the location of the change in the images instead of clicking a button and then indicating the change by choosing from a list of items. We decided to modify the task this way in order to 1) decrease the likelihood that participants respond correctly by chance, and 2) reduce the

length of the experiment. Another modification we made is that, after completion of the task, participants were asked to indicate whether they double-checked their correctness before clicking on the change in the images on a 4-point scale (0: never, 1: sometimes, 2: often, 3: always). At the end of the study, participants were thanked for their participation, debriefed, and provided with a completion code which they used to claim their payment (at a rate of £7.50/hour). The completion of the study took approximately 35 minutes.

4.3.4 Statistical analysis

The sample size of the study was determined based on the effect size obtained in our previous change blindness study (Chapter 3). We recruited 616 participants to achieve 80% power (at alpha=0.05, r=-.1, pre-registered one-tailed test).

All analyses were performed in Python 3.6.9.

We used mean reaction time on correct trials in the change blindness task as the dependent variable. We determined the internal consistency of the measure by calculating the split-half reliability of mean reaction times on correct trials over 100,000 random splits, using the scipy1.5.2 package.

Simple linear regressions (one regression per each of the two questionnaires) were conducted using the statsmodels v.0.11.1 package to test which questionnaire scores are significantly associated with task performance. We then performed multivariate regression analyses, including all predictor and control variables. We repeated this in a mega-analysis in which we pooled raw data across our first and follow-up change blindness experiment. In our preregistered protocol of the change blindness replication study, we confined our one-tailed hypothesis testing to the original “surroundings”

condition without including a plan for testing the effect of condition on the correlation between mean reaction time and depression score. In this paper we tested across all conditions and then calculated Steiger's Z to establish whether the correlations between symptom questionnaires and mean reaction time were significantly different from each other across conditions.

To further establish the robustness of the association between mean reaction time in the change blindness task and self-reported depression and anxiety scores, we conducted a permutation analyses. We determined an empirical null distribution of Pearson's r correlation between mean reaction time and BDI-II and STAI-T scores by randomly permuting mean reaction time over 100,000 iterations. We then calculated the p-value of the correlation observed in our original sample.

4.4 Results

4.4.1 Replication study

We tested a sample of 616 participants with mean BDI-II score=12.9 (SD=910.3) and mean STAI-T score=48.1 (SD=12.9). Two (0.3%) participants have a diagnosis of schizophrenia, a diagnosis of bipolar disorder was reported by 10 (1.6%) participants, 19 (3%) participants have a neurological disorder, and 23 (3.7%) participants have been diagnosed with a learning disability.

The Spearman-Brown corrected split-half reliability of correct trials on the change blindness task was $r_{SB} = 0.59$.

We found a significant (pre-registered one tailed) association between mean reaction time and self-reported depression score (B=-15, 95%CI -∞ to -15, p=0.045) (**Figure 4.1, Table 4.1**). Mean reaction time was also significantly associated with self-reported anxiety scores in a two-tailed unadjusted linear regression analysis (B=-17, 95%CI -31 to -2, p=0.022) (**Figure 4.2**). (We conducted a permutation analysis and found a significant Pearson's r correlation between mean reaction time and BDI-II (p=0.034, preregistered one-tailed test) as well as STAI-T (p=0.023, two-tailed).)

The correlations between mean reaction time and symptom measures were not significantly different from each other when the task was broken down into different conditions. By calculating Steiger's Z we did not find that the correlations between mean reaction time and symptom scores were statistically significantly different in the "humans" and "non-social" conditions relative to the original "surroundings" condition (BDI-II: "surroundings" vs "humans": test≠0, t(615)=0.3, p=0.790; "surroundings" vs "non-social": test≠0, t(615)=0.7, p=0.516; STAI-T: "surroundings" vs "humans":

test≠0, t(615)=0.5, p=0.610; “surroundings” vs “non-social”: test≠0, t(615)=0.9, p=0.362).

Mean reaction (ms) time in change blindness task			
Replication study			
Unadjusted			
	B	**CI**	**p**
BDI-II	-15	-∞ to -15	0.045*†
STAI-T	-17	-31 to -2	0.022*
Adjusted			
BDI-II	1	-28 to 32	0.915
STAI-T	-10	-35 to 14	0.400
Strategy	281	78 to 483	0.007**
Age	63	48 to 78	<0.001***
Gender	-239	-610 to 130	0.203
Mega-analysis			
Unadjusted			
	B	**CI**	**p**
BDI-II	-20	-35 to -5	0.007*
STAI-T	-17	-28 to -5	0.006*
Adjusted			
BDI-II	-11	-37 to 14	0.389
STAI-T	-2	-22 to 19	0.866
Age	53	39 to 67	<0.001***
Gender	-191	-487 to 104	0.204
Experiment	-278	-615 to 59	0.106

Table 4.1 Change blindness task regression analyses in the replication study and mega-analysis: Unadjusted and adjusted linear regression coefficients (B) with confidence intervals (CI) and p-values (p). Individuals with higher "Strategy" scores (ranging from 0 to 3) had a greater tendency to double-check he change in the images before responding. †pre-registered one-tailed test

In other words, individuals who scored higher on symptoms of depression and anxiety were *faster* at identifying changes in the images.

However, as shown in **Table 4.1**, these effects were not statistically significant after including all predictor variables (depression, anxiety), age, gender and strategy (i.e., how often the participant double-checked the change before clicking on it) in our linear regression model (BDI-II: B=4, 95%CI -26 to 34, p=0.802; STAI-T: B=-12, 95% CI -36 to 13, p=0.343). In the adjusted analysis, we found that older participants were significantly slower at identifying changes in the images (B=59, 95%CI 44 to 73,

p<0.001). We also found that those who more often double-checked the change before clicking on it had a significantly slower mean reaction time (B=281, 95%CI 78 to 483, p=0.007). We adjusted for this variable in our analysis because we were primarily interested in change blindness per se, i.e., the time it takes for an individual to notice a change in a visual stimulus, unconfounded by their tendency to double-check their correctness, which in itself could be a behaviour related to anxiety. It is worth noting that we found no statistically significant relationship between strategy (i.e., double-checking tendency) and anxiety scores when we regressed strategy onto STAI-T scores (B=0.002, 95%CI -0.004 to 0.007, p=0.562).

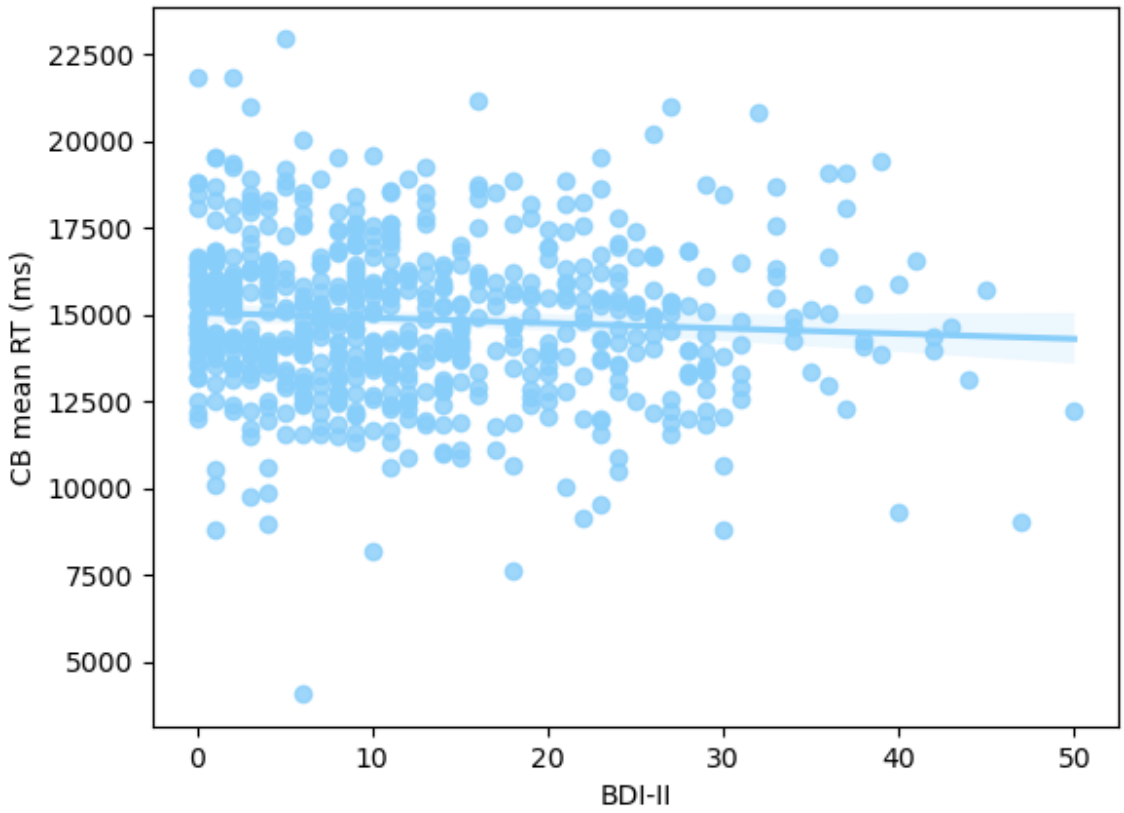

Figure 4.1 Association between change blindness task performance and depression symptoms in replication study: Mean RT~BDI-II regression (B=-15, 95%CI -∞ to -15, p=0.045).

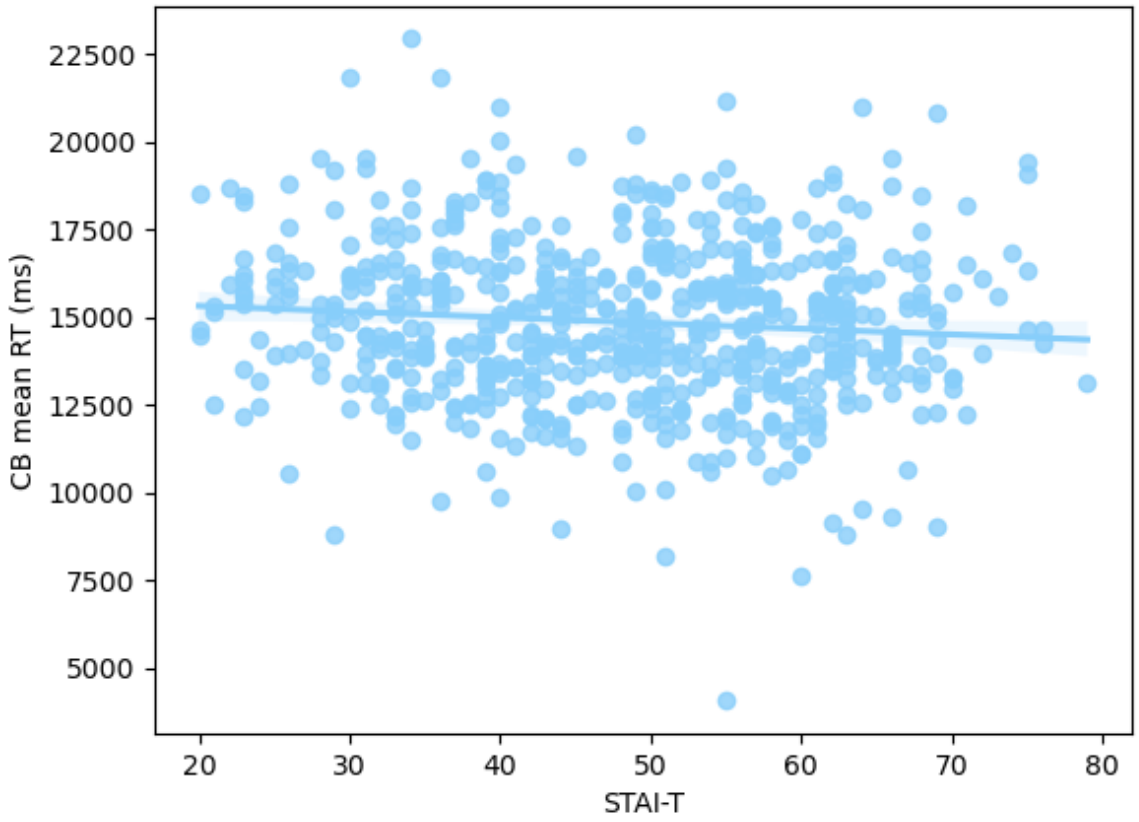

Figure 4.2 Association between change blindness task performance and anxiety symptoms in replication study: Mean RT~STAI-T regression (B=-17, 95%CI -31 to -2, p=0.022).

4.4.2 Mega-analysis

Our mega-analysis included 1161 participants, and each regression model included the study they participated in as a covariate of no interest. In the unadjusted linear regression analysis, including all conditions, mean reaction time was significantly associated with self-reported depression scores (B=-20, 95%CI -35 to -5, p=0.007) (**Figure 4.3, Table 4.1**). We found a similar association between mean reaction time and self-reported anxiety scores (B=-17, 95%CI -28 to -5, p=0.006) (**Figure 4.4**). Individuals who scored higher on symptoms of depression and anxiety were *faster* at identifying changes in the images.

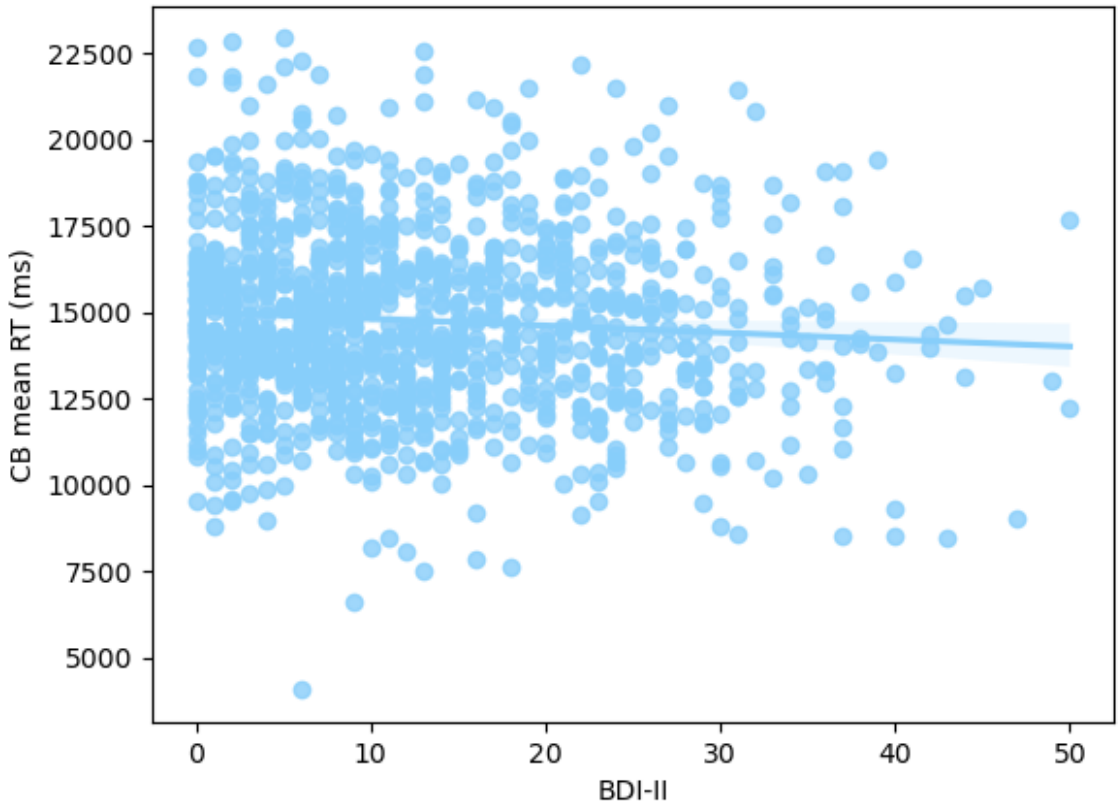

Figure 4.3 Association between change blindness task performance and depression symptoms in mega-analysis: Mean RT~BDI-II regression (B=-20, 95%CI -35 to -5, p=0.007).

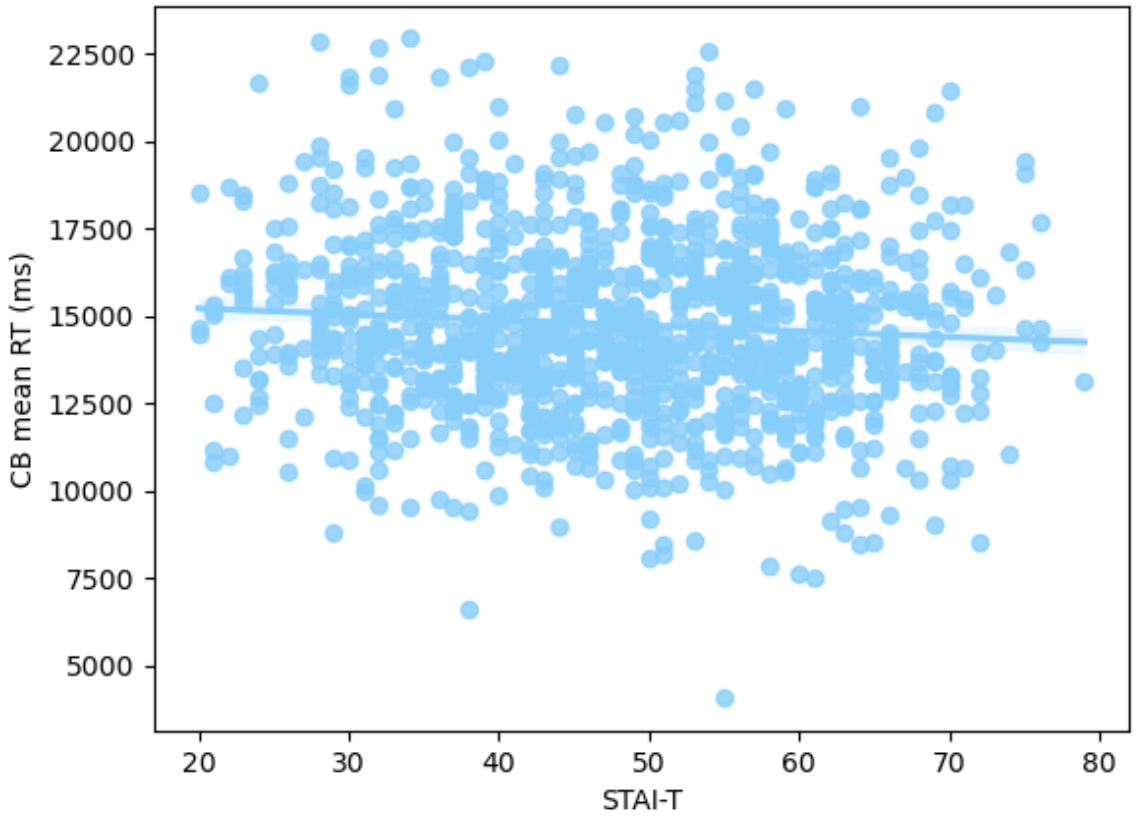

Figure 4.4 Association between change blindness task performance and anxiety symptoms in mega-analysis: Mean RT~STAI-T regression (B=-17, 95%CI -28 to -5, p=0.006).

However, again, these effects were not statistically significant after adjusting for age and gender (BDI-II: B=-11, 95%CI -37 to 15, p=0.394; STAI-T: B=-2 95%CI -23 to 19, p=0.860). In the adjusted analysis, we found that older participants were significantly slower at identifying changes in the images (B=53, 95%CI 38 to 67, p<0.001). Pearson's r correlation with age was r=-0.10 for depression (**Figure 4.5**) and r=-0.12 for anxiety (**Figure 4.6**).

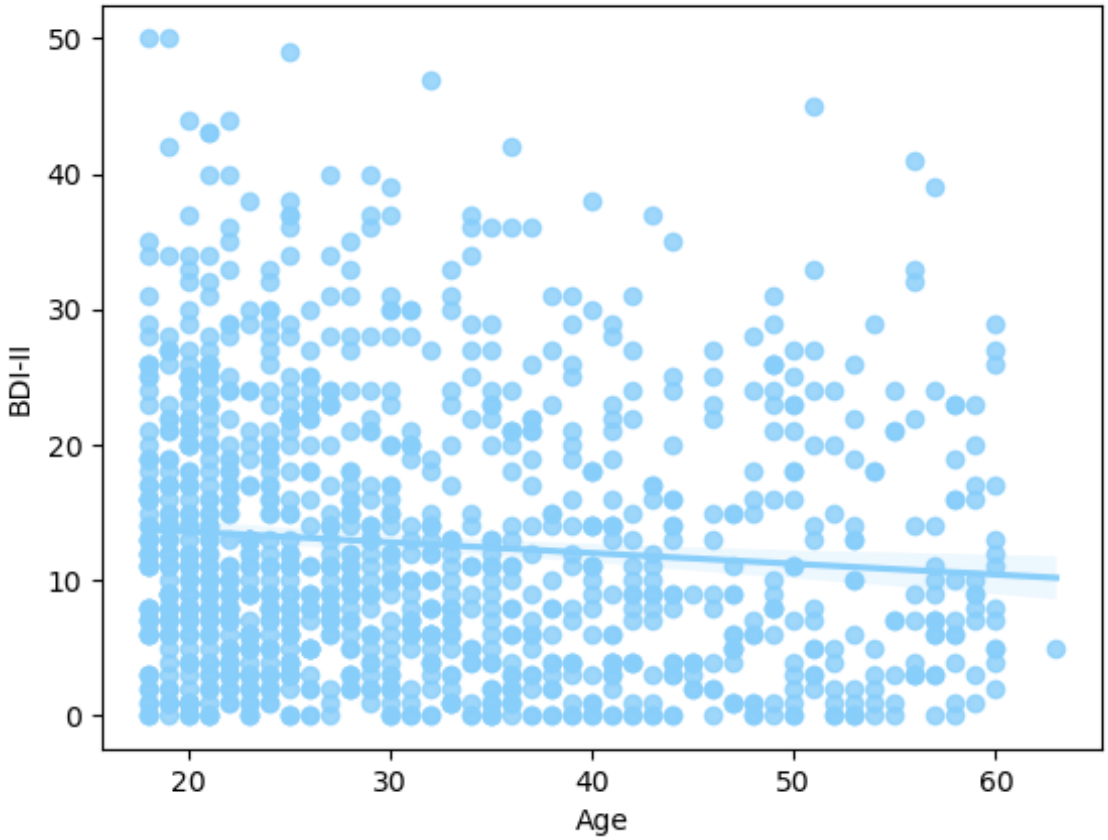

Figure 4.5 Association between depression symptoms and age in mega-analysis: BDI-II~Age regression (95% confidence interval).

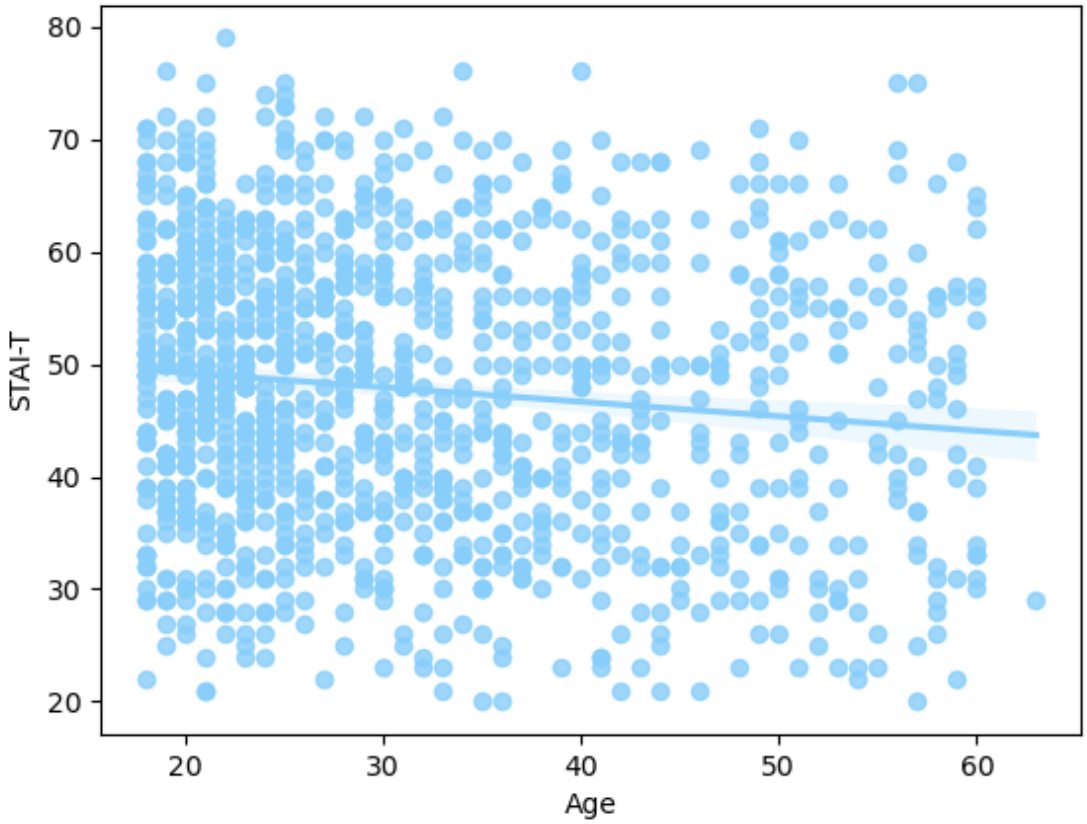

Figure 4.6 Association between anxiety symptoms and age in mega-analysis: STAI-T~Age regression (95% confidence interval).

4.4.3 Exploratory analyses

Correlation between questionnaires:

We found similar correlations between questionnaires as we did in our previous online study (Chapter 3). As shown in **Figure 4.7**, depression and anxiety scores were the most highly related (replication study: r=0.83; mega-analysis: r=0.83). MCQ-30 total scores were also highly correlated with depression (replication study: r=0.58; mega-analysis: r=0.56) and anxiety (replication study: r=0.67; mega-analysis: r=0.62). In addition, there was a strong association between negative beliefs about the danger and uncontrollability of worry and depression (replication study: r=0.62; mega-analysis: r=0.64) and anxiety (replication study: r=0.75; mega-analysis: r=0.75).

Age was *more strongly* negatively correlated with each of the metacognition scales (r ranging from -0.13 to -0.26) and, relatedly, the strategy used while completing the change blindness task (r=-0.19), than with depression (r=-0.09) and anxiety (r=-0.12) symptoms.

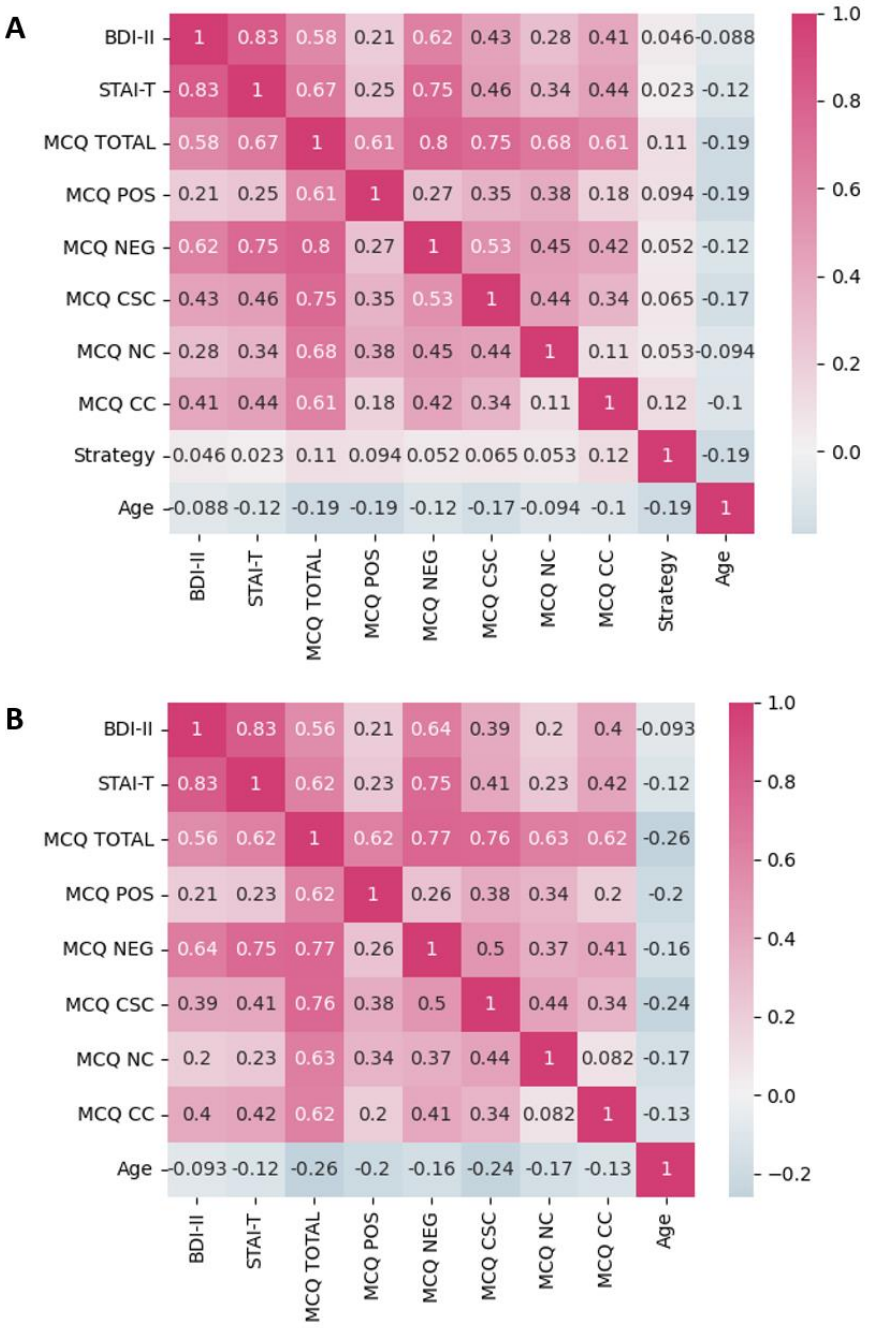

Figure 4.7 Heatmap of correlations between questionnaires and age in replication study and mega-analysis. **A:** Replication study, **B:** Mega-analysis. Heatmap of correlations between questionnaires and age in replication study. BDI-II = Beck Depression Inventory-II; STAI-T = State-Trait Anxiety Inventory – Trait subscale; MCQ Total = Metacognitions Questionnaire (MCQ) – Total scores; MCQ POS =MCQ 'Positive beliefs about worry' subscale; MCQ NEG = MCQ 'Negative beliefs about uncontrollability and danger of worry' subscale; MCQ CSC = MCQ ' Cognitive self-consciousness' subscale; MCQ NC = MCQ 'Need to control thoughts' subscale; MCQ CC = MCQ 'Cognitive confidence' subscale; Strategy = How often a participant double-checked the change before clicking on it, indicated on a 4-point scale (never: 0, sometimes: 1, often: 2, always: 3)

Exploratory analyses including all covariates:

For the replication study and mega-analysis, we performed multiple linear regression analyses, including all predictor variables as well as covariates of no interest – age, gender, experiment (in the case of the mega-analysis), shown in **Table 4.2**. Depression and anxiety symptoms remained not significantly associated with mean reaction time in the change blindness task. Older participants were significantly slower at identifying changes in the images (replication study: B=63, 95%CI 48 to 78, p<0.001; mega-analysis: B=52, 95%CI 38 to 67, p<0.001).

In the replication study, we found that those with higher scores for cognitive self-consciousness were significantly slower at spotting changes in the images (B=76, 95%CI 17 to 136, p=0.012). In addition, those who were more likely to double-check the changes in the images before clicking on them had a significantly higher mean reaction time (B=287, 95%CI 83 to 490, p=0.006). However, neither of these effects survived after correcting for multiple testing.

In the mega-analysis we found that individuals who scored higher on the "positive beliefs about worry" subscale of the MCQ-30 were significantly faster at identifying changes in the images (B=-40, 95%CI -79 to -2, p=0.041) although, again, this effect disappears after correcting for multiple testing.

Mean reaction (ms) time in change blindness task			
Replication study			
	B	**CI**	**p**
BDI-II	-3	-33 to 27	0.837
STAI-T	-6	-35 to 23	0.677
MCQ total	-2	-15 to 12	0.783
MCQ positive beliefs about worry	-40	-86 to 7	0.095
MCQ negative beliefs about uncontrollability and danger	-16	-71 to 38	0.555
MCQ cognitive self-consciousness	76	17 to 136	0.012*
MCQ need to control thoughts	-38	-89 to 13	0.144
MCQ lack of cognitive confidence	16	-71 to 38	0.459
Strategy	287	83 to 490	0.006**
Age	63	48 to 78	<0.001***
Gender	-212	-586 to 162	0.266
Mega-analysis			
	B	**CI**	**p**
BDI-II	-14	-40 to 12	0.306
STAI-T	-4	-28 to 20	0.746
MCQ total	-1	-13 to 10	0.833
MCQ positive beliefs about worry	-40	-79 to -2	0.041*
MCQ negative beliefs about uncontrollability and danger	6	-41 to 52	0.811
MCQ cognitive self-consciousness	37	-13 to 87	0.142
MCQ need to control thoughts	-23	-65 to 19	0.283
MCQ lack of cognitive confidence	19	-15 to 53	0.276
Age	52	38 to 67	<0.001***
Gender	-188	-490 to 113	0.220
Experiment	-270	-609 to 69	0.118

Table 4.2 Exploratory regression analyses including covariates in replication study and mega-analysis: Multivariate linear regression coefficients (B) with 95% confidence intervals (CI) and p-values (significance levels marked by * before correcting for multiple testing).

4.5 Discussion

We found that higher self-reported depression and anxiety scores were associated with faster noticing of changes in images across all conditions. This is consistent with the results of our first change blindness study in which we found that individuals with higher depression scores were quicker at identifying changes. The effects of depression and anxiety on task performance were statistically significant in our pooled mega-analysis. However, in all instances, these effects were not robust to the effects of age.

The effect of depression and anxiety symptoms on change blindness may be explained by an increased tendency to scan the environment for potential threats due to hypervigilance, a characteristic of anxiety (Bar-Haim et al., 2007; Roy et al., 2008). Previous research has found an association between a better ability to detect changes in the visual environment and 1) less distractibility and 2) more robust visual representations which enable the increased detection of mismatches between the existing visual representation and incoming signal (Andermane et al., 2019). Hypervigilance, less distractibility and stronger visual representations may all be interrelated processes linked to the symptoms observed in depression and anxiety.

In the previous chapter we speculated that the effects may be driven by the social content of the images. We proposed that individuals with depression and anxiety may be faster at identifying changes in the surroundings of humans because they are more likely to pay increased attention to the surroundings due to threat monitoring and/or decreased attention to people due to social anhedonia (Kupferberg et al., 2016). However, in this study we did not find evidence of this. The effect of depression and anxiety was comparable across all conditions, regardless of whether the change appeared in humans, in the surroundings of humans or in non-social images. This suggests that more severe

depression and anxiety symptoms may be associated with facilitated detection of changes in the environment in general.

However, it is critical to note that we found no statistically significant evidence for these associations after controlling for age and gender in all studies. It is possible that we lacked statistical power to detect an association when controlling for confounding variables. Older individuals were significantly slower at identifying changes in the images. Therefore, it is possible that the association between self-reported depression and anxiety scores and reaction time is partially or fully driven by age. However, it is worth noting that the correlation with age was relatively low for both depression (r=-0.09) and anxiety (r=-0.12). Future studies could further investigate this relationship by using age-matched case-control samples, which would select for the presence of depression and anxiety while simultaneously controlling for the age confound that arises due to the correlation between age and emotional disorders.

Preliminary results from our exploratory analyses about metacognition in our replication study reveal that those with higher levels of cognitive self-consciousness may be significantly *slower* at identifying changes in images. This result is consistent with previous findings suggesting that lower distractibility is associated with better performance on a change blindness task (Andermane et al., 2019). It is possible that individuals who are more likely to monitor their own cognitive processes are distracted by paying attention inwardly and take longer to notice changes in the external environment. In addition, in our mega-analysis we found that individuals who report more positive beliefs about the usefulness of worry may be significantly *faster* at noticing changes in the visual environment. It could be the case that a belief in the positive effects of worry as a metacognitive strategy is related to hypervigilance

observed in anxiety, which may facilitate the detection of changes in the environment. However, it important to note that neither of these metacognitive effects were robust enough to survive correction for multiple testing. Therefore, future studies are needed to investigate the relationship between change blindness and metacognition.

Further investigation of the relationship between depression and anxiety, the ability to detect changes in the environment and metacognition could inform us about cognitive underpinnings of these disorders relevant to therapy outcomes. In addition, as proposed in the previous chapter, it is possible that a better ability to detect changes in the environment could be used effectively in CBT, which involves instructing patients to bring attention to previously unnoticed features in the environment during behavioural experiments and to thoughts and internal processes that usually lie outside of conscious awareness.

4.5.1 Strengths and limitations

One limitation of our study design is that our online sample recruited on the Prolific platform is unlikely to be representative of the general UK population, even though our inclusion criteria were minimal (understanding English and access to computer). As a result, our findings may not be generalisable.

It is also important to note that our data may be noisy due to participants' lack of attention or non-compliance with the task. We did not use "catch" questions to test attention in the questionnaires, nor did we include practice trials or questions about whether participants understood the task instructions. However, it is unlikely that participants responded correctly by change in this modified design of the change blindness task requiring participants that they click on the location of the change in the image.

In addition, we did not collect data on depression and anxiety disorder diagnoses. Therefore, future studies are needed to determine whether our results are generalisable to clinical presentations of depression and anxiety disorders. Also, our analyses did not account for co-morbid diagnoses of schizophrenia, bipolar disorder, learning disability and neurological disorders (affecting 0.3-3.7% of participants), which could have biased our results.

A further limitation is that due to the length and difficulty of the change blindness task, we did not include measurements of potential confounding variables, such as working memory or IQ. Finally, the cross-sectional nature of our study makes it impossible to draw conclusions about the causal direction of the effects found.

However, it should be noted that one key strength of this study is that we replicated, in accordance with our pre-registered hypothesis and sample size (https://osf.io/s86v9/), the effect found in our previous online study (Chapter 3) about the association between higher levels of depressive symptoms and a faster detection of changes in images. Replication is a critical response to the 'replication crisis' in psychology where it has been previously found that only 36% of replications had statistically significant results (Open Science Collaboration, 2015). This is perhaps especially important in unselected online studies where participant data is noisy and there are concerns about data quality due to inattentive responding which can lead to spurious associations between task performance and symptom measures (Zorowitz et al., 2021). Replication is also essential in larger samples where trivially small effects can appear significant. Having found the same effect twice increases our confidence in the effect. However, as highlighted above, with this design it is impossible to rule out potential confounders, such as age. To do this, we need to identify groups who are high and low on anxiety but

who do not differ in age. This need sets up the case-control design presented in the next chapter.

4.5.2 Summary

To summarise, we replicated the effect that more depressed and anxious individuals are faster to identify changes in images (regardless of the content of image), but we cannot rule out that this effect is due to an age confound.

Chapter 5: Change blindness and metacognition in mood and anxiety disorders: A case-control study

5.1 Abstract

Introduction: Depression and anxiety disorders are associated with changes in cognition. In addition to self-reported questionnaires, which are subject to biases, cognitive tasks have the potential to be used in clinical practice to 1) understand more about the cognitive processes underlying these disorders and 2) discern the mechanisms through which psychological therapy works as well as to 3) provide personalised treatment. As an initial step towards this, we conducted a pilot case-control study comparing patients with depression and generalised anxiety disorder with healthy controls. We looked at performance on a change blindness task, to follow up on previous preliminary findings (Chapters 3, 4) suggesting that depression and anxiety are associated with a better performance on this task. In addition, we included a task to investigate group difference in metacognitive efficiency, which has been linked to depression and anxiety disorders. As metacognition could also play a crucial role in therapy outcomes, we introduced a within-subjects manipulation to examine whether metacognitive performance can be improved as a result of receiving additional cognitive behavioural therapy-like instruction.

Methods: N=40 participants, with N=20 in the patient and N=20 in the healthy control groups, completed the change blindness task and the metacognition task. We used an independent samples t-test and a non-parametric Mann-Whitney *U* test to test if there was a difference in performance between the groups on the change blindness task. We conducted mixed effects ANOVA analysis to investigate the effects of group and condition on metacognitive efficiency.

Results: There was no statistically significant difference in mean reaction time on the change blindness task between groups (t(38)=1.3, p=0.188); *U*=224, p=0.525). There was also no evidence of a main effect of group (F(1,35)=0.36, p=0.553), condition (F(1,35)=0.15, p=0.700) and their interaction (F(1,35)=0.34, p=0.566) on metacognitive efficiency.

Conclusion: We found no difference in change blindness and metacognition between patients with depression and anxiety disorders and healthy controls. There was also no evidence that metacognitive insight can be improved through voluntary effort as a result of instruction. Therefore, focusing on these cognitive processes may not be valuable clinically. However, our study may not have had sufficient power to detect effects in the range observed in clinical studies.

5.2 Introduction

Depression and anxiety are characterised by changes in cognition (Bar-Haim et al., 2007; Rock et al., 2014), among other symptoms. The theory behind cognitive behavioural therapy, the most common evidence-based psychological therapy for depression and anxiety, posits that cognition plays a role in the development and maintenance of these disorders (Beck, 1979; Beck et al., 2005). One of the goals of cognitive behavioural therapy, therefore, is to correct these cognitive biases. Most of the clinically relevant data about the cognitive characteristics of depression and anxiety are based on self-reported measures provided by patients and observations made by clinicians. However, in addition to questionnaires, cognitive processes can be increasingly more precisely measured by cognitive tasks. As discussed in the previous chapters, these tasks are not yet integrated with clinical practice despite their potential to help us 1) discern the cognitive processes underlying depression and anxiety, including causal relationships, 2) understand what aspects of cognition are modified by psychological therapy, and 3) provide personalised treatment.

Previous research has shown that cognitive changes in depression and anxiety are present in the domain of attention (Eysenck et al., 2007; Koster et al., 2005; Roy et al., 2008). We found evidence for this in the unscreened samples of two cross-sectional studies (Chapters 3, 4) in which individuals with higher self-reported depression and anxiety scores were *faster* at identifying changes in images in a change blindness task. However, this effect disappeared after controlling for age, and given the design of our previous studies, it is not possible to tell from our findings whether the change blindness effect is due to age. Moreover, we do not know to what extent continuous symptom measures in unscreened samples can inform our understanding of individuals who meet

current clinical criteria for mood anxiety disorders. Therefore, in the current study, our aim was to further investigate the change blindness effect in a case-control study with age-matched samples.

In addition to changes in attention, previous findings suggest that depression and anxiety are characterised by changes in metacognition, i.e., the way people reflect on their own cognition (Rouault et al., 2018; Wells, 2000). Various maladaptive metacognitive processes have been reliably linked with depression and anxiety, e.g., excessive monitoring of one's own thoughts and a lack of confidence in one's own cognition (Wells, 2000). Consistent with this, in our previous two studies discussed in Chapters 3 and 4, we found correlations between depression and anxiety symptoms and maladaptive metacognitive processes ranging from 0.2 to 0.62. However, these clinically relevant processes are mainly measured through self-report.

Currently, cognitive tasks in experimental research measure only a very narrow aspect of metacognition. Most such studies ask people to reflect on their own performance on a simple task, and their judgements about their own accuracy are used to quantify their 1) metacognitive confidence, i.e., how confident they are in general, and 2) metacognitive efficiency, i.e. the extent to which fluctuations in their subjective confidence ratings reflect fluctuations in their objective performance on the task (Fleming & Lau, 2014). Not much research has been done on the relationship between mood and anxiety disorders and metacognitive confidence and efficiency, and preliminary findings are mixed. Depression and anxiety have been linked to lower metacognitive confidence and efficiency (Barrientos et al., 2022; Culot et al., 2021; Reyes et al., 2020). However, some findings suggest that anxious people have lower metacognitive confidence but higher metacognitive efficiency, suggesting that they are better able to track fluctuations

in their own performance while being less confident in general (Rouault et al., 2018). To further investigate this relationship, we included a metacognition task in our study.

In addition to altered metacognitive processes in depression and anxiety, we are also interested in the role of metacognition as a potential mechanism underlying psychological therapies for mood and anxiety disorders. A central feature of psychological therapies founded on cognitive models of depression and anxiety, most notably cognitive behavioural therapy, is to encourage patients to recognise and evaluate their own cognitive tendencies. This requires that patients make an effort to accurately reflect on their cognition. However, to our knowledge, there is currently no research on whether metacognitive insight can be improved voluntarily, as a result of the kind of instruction that patients receive during psychological therapy. So, as a secondary aim, we also looked at whether participants can voluntarily improve their metacognitive efficiency (i.e., insight into their own performance) in the metacognition task.

Overall, in this study, we conducted an online case-control study to see if we can replicate the continuous, unscreened change blindness effect (Chapters 3, 4) in an age-matched clinically screened sample, predicting faster reaction times in the patient group relative to the healthy control group. We also aimed to identify differences in metacognition between the groups. Finally, as an additional aim, we investigated if metacognition can be voluntarily improved.

5.3 Methods

5.3.1 Study design

This was a case-control pilot study with a patient and a healthy control group. After answering an online clinical screening questionnaire about psychiatric health, eligible participants were directed to an online experiment in which they completed two cognitive tasks, relating to change blindness and metacognition.

5.3.2 Participants and recruitment

Participants were recruited through various research study databases. They had to be aged between 18 and 64 years, speak fluent English, have the ability to give written informed consent and be registered with a general practitioner. Participants were excluded from the study if they had comorbid neurological disorders. This was a convenience sample completed towards the end of my PhD. As such we recruited as many participants as possible. However, based on an a priori power calculation, we needed 64 participants in both groups to detect a Cohen's *d* effect size of 0.5 using a two-tailed test with alpha=0.05 and 80% power. This effect size lies in the middle of the range of the Cohen's *d* effect sizes found for a variety of cognitive processes in depressed patients relative to healthy controls in a systematic review by (Rock et al., 2014). The final sample ended up being N=20 per group, which meant that we were powered for a Cohen's *d*=0.9, and underpowered to detect *d*=0.5.

We used the Revised Clinical Interview Schedule (CIS-R) to screen participants. The CIS-R is a standardised interview that generates a total score as well as categorical diagnoses based on ICD-10 criteria (for details of the measure, see Chapter 2). The patient group included individuals with a diagnosis of at least one of the following

disorders: depression, generalised anxiety disorder, mild generalised anxiety disorder. Participants were also included in the patient group if they met criteria for 'mild neurosis', which is defined as a total CIS-R score of 12 or above, indicating a clinically significant level of distress, without matching criteria for any of the ICD-10 diagnoses measured by the CIS-R. Individuals in the patient group were *not* excluded based on comorbidities, i.e., a person with a diagnosis of, for example, depression and obsessive-compulsive disorder was eligible to participate. The control group included healthy individuals with no psychiatric diagnosis and a total CIS-R score below 12.

5.3.3 Procedure

The study was approved by the University College London Research Ethics Committee (Ethics Project ID number: 15253/002). After expressing their interest in the study via an online form, participants had a brief telephone pre-screening to determine their basic suitability for the full screening session. Eligible participants were then invited to the screening session which consisted of providing online consent and filling in the online version of the CIS-R. Following this, individuals who were sorted into the patient or control groups were given a link directing them to Gorilla (www.gorilla.sc), the platform on which the experiment was hosted. Participants completed the change blindness task and the metacognition task, in this order. At the end of the study, participants were thanked for their participation, debriefed and paid through PayPal at a rate of £8/hour. The completion of the study took approximately 60 minutes.

5.3.4 Cognitive tasks

Change blindness task:

As described in Chapter 2, in the change blindness task participants were asked to spot and indicate the changes occurring in a series of flickering images by clicking on the location of the change in the image (**Figure 2.3/B** on page 38).

Metacognition task:

In each trial of the metacognition task, participants had to respond in a two-alternative forced choice perceptual discrimination task by deciding which of two squares contained more dots (for details of the task, see Chapter 2, **Figure 2.4** on page 41). They then indicated their confidence in the accuracy of their own answer on a continuous sliding scale from "Guess" to "Certain".

To investigate whether metacognitive accuracy can be improved voluntarily, participants completed the exact same task across two conditions with different instructions. In the first condition, "pre-instructions", participants were given basic instructions on how to complete the task. In the second condition, "post-instructions", participants were given additional insight about the nature of the task and were instructed to rate their confidence as accurately as they can. The additional instructions were the following:

"We know that people who suffer from depression and anxiety often have biases in the way they think. It can be hard to recognise these biases in our own thinking, and one of the goals of psychological therapy is to help people better understand the way they think.

When you rate your own confidence about whether you chose the right answer in this task, you are reflecting on your own thinking. ***For the remainder of the task, please try as best as you can to rate your confidence in your own choice accurately.****"*

The task started with a practice phase of 70 trials during which the signal strength was set for each individual to achieve ~71% accuracy. The main task consisted of 180 trials in total with 90 trials per condition (pre- and post-instructions), each divided into two blocks of 45 trials.

5.3.5 Statistical analysis

All analyses were performed in Python 3.6.9.

After checking for normality and homogeneity of variance assumptions (Wilcoxon test), we conducted an independent samples t-test to determine whether the age distributions of the two groups were significantly different.

Change blindness task:

We used an independent samples t-test to determine whether there was a significant difference in mean reaction time on correct trials between the two groups. As normality assumptions were not satisfied, we also conducted a non-parametric Mann-Whitney *U* test to test this difference.

Metacognition task:

Performance was defined as percentage of correct responses on the perceptual discrimination task.

Confidence ratings were used to measure metacognitive bias and metacognitive efficiency. Metacognitive bias is the general tendency to give high or low confidence ratings (irrespective of fluctuations in performance). Metacognitive bias was simply measured by mean confidence. Confidence ratings given on a continuous scale were rounded to integers on a 7-point scale from 0 (“Guessing) to 6 (“Certain).

Metacognitive efficiency is a quantitative measure of how closely subjective confidence ratings map onto fluctuations in objective performance on the perceptual discrimination task. In other words, an individual with high metacognitive efficiency will report higher confidence after correct responses and lower confidence after incorrect responses. We measured metacognitive efficiency by computing meta-d' - d' (Maniscalco & Lau, 2012). According to signal detection theory, the d' score is a measure of the ability to discriminate the signal from noise (i.e., give the correct answer). It reflects the objective, first-order, performance on the task. The meta-d' score measures an individual's ability to discriminate their responses as correct or incorrect. A person with perfect metacognition would use all the sensory information available for the first-order decision on the task when judging the accuracy of their response. Therefore, in an ideal case meta-d' would be equal to d' (i.e., meta-d' - d' = 0 reflects perfect metacognitive efficiency). If meta-d' < d', it indicates that some of the sensory information is lost when making metacognitive judgements.

For each measure (performance, metacognitive bias, metacognitive efficiency), we tested the main effects of group and condition as well as their interaction effect using 1) mixed effects ANOVA analysis as well as 2) the F1-LD-F1 model of the naprLD package (Noguchi et al., 2012), which is a fully non-parametric analysis of variance type test.

5.4 Results

The total sample included N=40 participants. The patient group included N=20 participants (18 female, 2 male) with a mean age of 31.9 (SD= 9.6) years. Ten participants had diagnoses of mixed generalised anxiety disorder and depression, 8 had generalised anxiety disorder without depression and 2 of them had depression without generalised anxiety disorder. Mean CIS-R score was 24.15 (SD=8.7). For context, possible total CIS-R scores range from 0 to 57, and a score of 12 or above indicates a clinically significant level of distress (Lewis et al., 1992). The control group included N=20 participants (15 female, 5 male) with a mean age of 35.0 (SD=11.7). Mean CIS-R score in the control group was 1.25 (SD=2.4).

There was no difference in the age distribution of the two groups (t(38)=0.9, p=0.365; **Figure 5.1**).

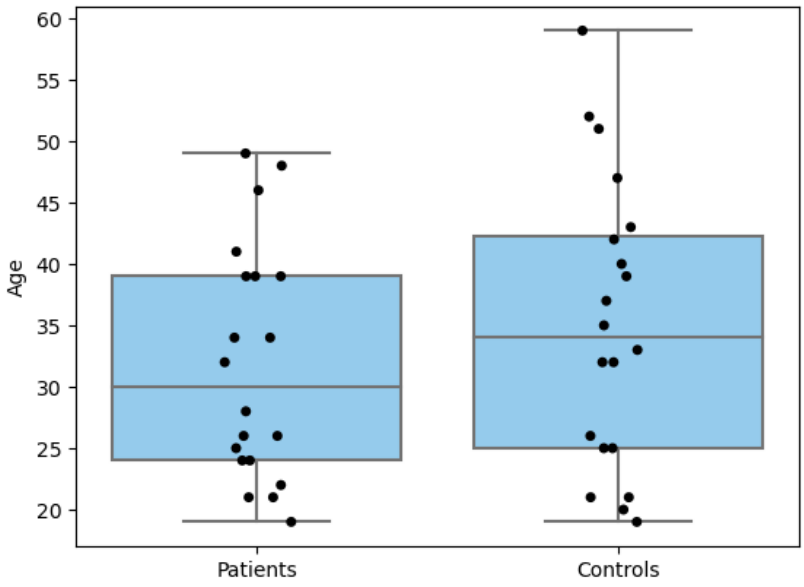

Figure 5.1 Age distribution in the patient and healthy control groups.

5.4.1 Change blindness task

Mean reaction time for correct trials was 14894 ms (SD=2823 ms) in the patient group and 13548 ms (SD=3870 ms) in the control group. We found no evidence for a difference in mean reaction time between the groups (**Figure 5.2**) using an independent samples t-test (t(38)=1.3, p=0.188) and a non-parametric Mann-Whitney *U* test (*U*=224, p=0.525).

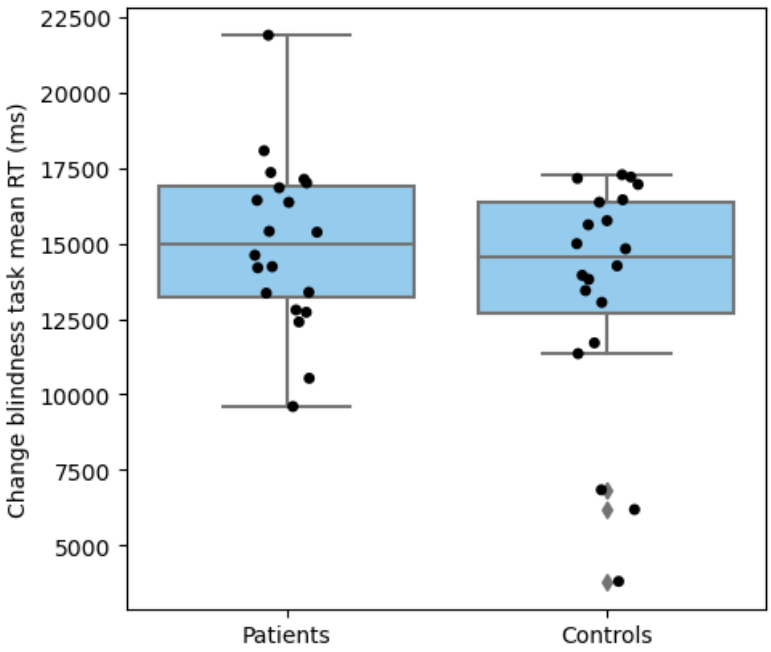

Figure 5.2 Mean reaction time in the change blindness task across patient and control groups.

5.4.2 Metacognition task

Three participants from the control group were removed from the analysis because it was not possible to calculate meta-d' - d' score from their data due to no variance in their subjective confidence ratings. The final sample consisted of N=20 patients and N=17 controls.

Performance on the perceptual discrimination task (% correct), mean confidence rating and metacognitive efficiency (meta-d' – d') across groups and conditions (pre- and post-instruction) are summarised in **Table 5.1** and shown in **Figure 5.3**. We found no main effect of group (ANOVA: $F(1,35)=0.36$, $p=0.553$; F1-LD-F1: $F(1, \infty)=0.70$, $p=0.404$) or condition (ANOVA: $F(1,35)=0.15$, $p=0.700$; F1-LD-F1: $F(1, \infty)=0.03$, $p=0.869$) on metacognitive efficiency (**Table 5.2**). There was also no evidence for an interaction effect between group and condition on metacognitive efficiency (ANOVA: $F(1,35)=0.34$, $p=0.566$; F1-LD-F1: $F(1, \infty)=0.94$, $p=0.332$). In addition, we found no evidence for an effect of either group or condition on performance on the perceptual discrimination task and mean confidence rating.

		Performance (% correct)		**Mean confidence**		**Metacognitive efficiency (meta-d' -d')**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Group	**Condition**						
Patients	**Pre**	73	10	3.28	0.59	-0.86	1.27
	Post	76	9	3.20	0.78	-0.65	0.78
Controls	**Pre**	73	9	3.42	0.66	-0.57	1.06
	Post	72	10	3.52	0.68	-0.62	1.09

Table 5.1 Descriptive statistics of the metacognition task: Performance, mean confidence and metacognitive efficiency.

	ANOVA		F1-LD-F1 model	
	F (df)	**p-value**	**F (df)**	**p-value**
	Performance (% correct)			
Group	0.37 (1, 35)	0.549	0.48 (1, ∞)	0.490
Condition	0.42 (1, 35)	0.521	0.93 (1, ∞)	0.335
Group x Condition	1.15 (1,35)	0.292	1.39 (1, ∞)	0.238
	Mean confidence			
Group	1.14 (1, 35)	0.292	1.60 (1, ∞)	0.206
Condition	0.02 (1, 35)	0.899	0.06 (1, ∞)	0.801
Group x Condition	0.14 (1, 35)	0.188	0.29 (1, ∞)	0.592
	Metacognitive efficiency			
Group	0.36 (1, 35)	0.553	0.70 (1, ∞)	0.406
Condition	0.15 (1, 35)	0.700	0.03 (1, ∞)	0.869
Group x Condition	0.34 (1, 35)	0.566	0.94 (1, ∞)	0.332

Table 5.2 Results of the metacognition task using ANOVA and F1-LD-F1 analyses.

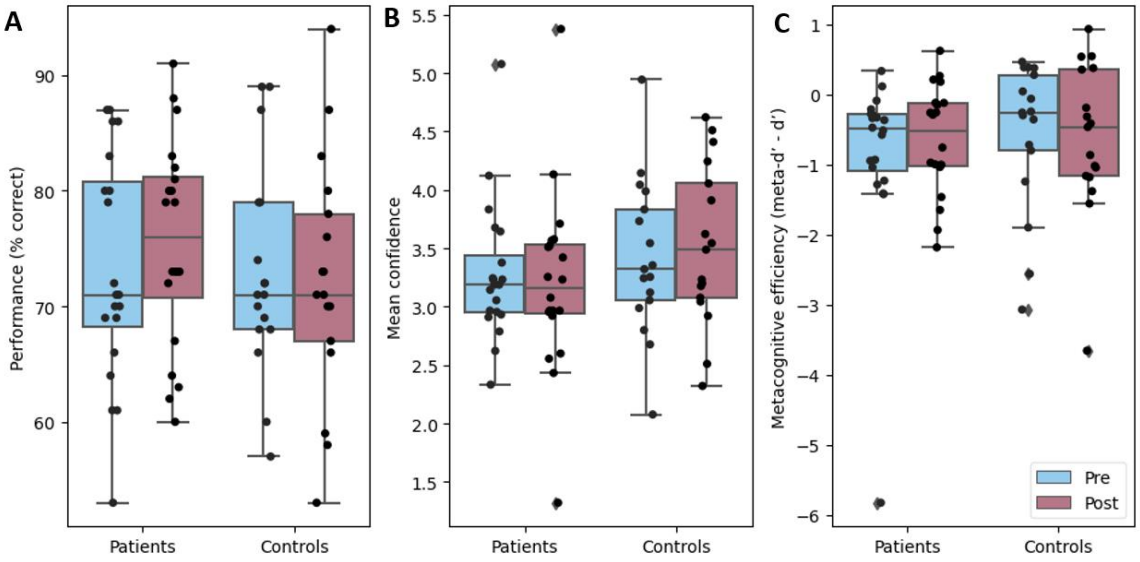

Figure 5.3 Performance, mean confidence and metacognitive efficiency in the metacognition task across groups and conditions.

5.5 Discussion

We found no difference in performance on the change blindness task between patients with depression and/or generalised anxiety disorder and healthy controls. There was also no evidence of a difference in metacognitive confidence and metacognitive efficiency between the two groups. Furthermore, task instructions had no effect on metacognitive performance.

We failed to find a change blindness effect in an age-matched clinically screened sample of patients with depression and/or generalised anxiety disorder and healthy controls. Previous research suggests that changes in cognitive processes in depressed patients relative to healthy controls have a small to medium effect size, averaging around 0.5 (Rock et al., 2014). Based on our a priori power calculations, we lacked statistical power to detect a difference of that size. Nevertheless, we had enough power to exclude a large effect size (0.9). The change blindness effect observed in our previous two cross-sectional studies of unscreened samples (Chapters 3, 4) may therefore have been driven by age. Alternatively, it is possible that the continuous symptom measures do not select for the same thing as diagnostic clinical screening measures. If anything, the effect was numerically in the opposite direction in the current study relative to our previous studies, i.e., the healthy control group was slightly faster at identifying changes in the images than the patient group. In light of our findings, focusing on change blindness in patients with depression and anxiety might not be clinically valuable. However, we may have failed to detect a clinically significant true effect due to small sample size.

There was no evidence of a difference in metacognitive confidence and efficiency between patients and controls. Although our study was conducted on a small sample

size, we can at least exclude a large effect size based on our findings. This suggests that this aspect of metacognition (i.e., subjective confidence in one's accuracy while performing a simple task) might also not be of clinical value. In addition, having enough statistical power to detect a medium effect size (0.4) for a within-subject difference, we observed no difference in metacognition pre- and post-instruction. We also found no interaction effect (i.e., no cross-over interaction) of group and condition (pre/post instruction). These findings indicate that, even if this aspect of metacognition was of clinical value, it would not be amenable to change through just voluntary effort as a result of instruction in either patients or healthy controls. The implication of this is that, to help patients improve their metacognitive insight, psychological therapies may need to use more specific instructions, such as encouraging people to take a third person point of view when evaluating their performance (Koriat & Ackerman, 2010).

5.5.1 Limitations

The most notable limitation of this study is that, based on our a priori power calculation, we were underpowered to detect a magnitude of difference in cognitive processes between patient and control groups in the range that has been observed in previous studies (Rock et al., 2014), i.e., small to moderate effect sizes. However, as discussed above, our sample size was large enough to exclude the presence of large effect sizes.

It is also worth mentioning that the patient group was quite heterogenous (participants with co-morbidities identified by the CIS-R, such as obsessive-compulsive disorder, were not excluded). Also, although participants with a neurological disorder were excluded at screening, we do not have data on co-morbid psychiatric diagnoses outside of those measured by the CIS-R (for details of the measure, see Chapter 2). Furthermore, individuals with only mild generalised anxiety disorder and 'mild

neurosis', defined as a CIS-R score of 12 or above indicating a clinically significant level of distress, were eligible to be included in the patient group. Still, the mean CIS-R score in the patient group was considerably higher than the cut-off point for clinically significant level of distress (Lewis et al., 1992). Nevertheless, heterogeneity and mildness of diagnoses may have contributed to our failure to detect a difference between patients and healthy controls.

Another limitation of our study design is that we had no precise way of checking data quality in the metacognition task, especially 1) whether participants gave honest confidence ratings in general and 2) whether they actually put more effort into giving accurate confidence ratings after the additional instructions. That said, the fact that participants' performance was around ~71% throughout the task, which is in accordance with the calibration phase, suggests that they completed the task attentively, rather than giving random answers. Also, participants were instructed to press different buttons at different times to move on to the next screen (including when the additional instructions were given), which served as a form of attention check.

5.5.2 Summary

We found no effect of diagnosis on change blindness or metacognition. It is possible that these cognitive processes are not associated with depression and anxiety disorders and are, therefore, of no clinical value. We also found no evidence that metacognitive insight can be improved through voluntary effort as a result of instruction. However, our study was likely underpowered to detect effects in the range expected clinically.

Chapter 6: General discussion

This chapter summarises the main results of the preceding experimental chapters, followed by limitations, implications, and directions for future research.

6.1 Summary of main results

I conducted three studies with the aim of exploring cognition in depression and anxiety. The first was a cross-sectional study in which I looked at the individual-level association between task performance and depression and anxiety symptoms by asking a large sample of unscreened online participants to complete a battery of three cognitive tasks that are thought to be relevant to depression and anxiety alongside self-reported symptom questionnaires. I then conducted a second cross-sectional online study in which I replicated the effects found in the first study. Finally, I ran a case-control study to investigate whether the depression- and anxiety-related effects found in unscreened online samples are present in a case control study comparing a clinical sample with healthy participants at the group level.

Below, I will briefly go through the primary inferences drawn from each study.

6.1.1 Chapter 3: Change blindness, reward bias, negative affective priming

The preliminary results of my first study suggested that individuals with more severe depressive symptoms are faster at spotting changes in images in a change blindness task. As change blindness paradigms are thought to measure attentional biases towards concern-related cues (Moss et al., 2011), this result could point to potential attentional processes underlying depression. However, the effect disappeared after controlling for age. Contrary to previous findings, my first study revealed no association between

depression and anxiety symptoms and performance on the reward bias and negative affective priming tasks. However, it is worth noting that the sample in my study was significantly more anxious and less depressed than the sample in a previous reward bias study (Daniel-Watanabe et al., 2022), which could explain why I failed to find a similar effect.

6.1.2 Chapter 4: Change blindness effect replication and mega-analysis

My second online study replicated the change blindness effect found in the previous one. The results suggest that individuals with higher self-reported depression and anxiety symptom scores are faster at identifying changes in images in the change blindness task in general, regardless of the content of the images. However, these effects were, again, not robust to controlling for age. I found the same association between depression and anxiety symptoms and performance on the change blindness task in a mega-analysis with pooled data from my first study and the replication study. Again, the effects were no longer present after I included age in my model. Therefore, it is unclear whether these effects are partially or fully driven by age.

6.1.3 Metacognition in Chapters 3 and 4

In these first two cross-sectional online studies I collected data on self-reported metacognitive processes that are associated with mood and anxiety disorders (Wells, 2000). I measured these using the 30-item Metacognitions Questionnaire (Wells & Cartwright-Hatton, 2004), which generates an overall score and a score for each subscale of the questionnaire (1) positive beliefs about worry, 2) negative beliefs about the uncontrollability and danger of worry, 3) cognitive self-consciousness, 4) a need to control thoughts, and 5) lack of cognitive confidence), with higher scores indicating an increased tendency to engage in maladaptive metacognitive processes related to

emotional disorders. I observed a negative correlation between age and overall questionnaire score as well as scores for each of its five subscales. These negative correlations were stronger than the negative correlations I found in my sample between age and depression/anxiety symptoms. In other words, older participants were less depressed and anxious than younger participants and *even less* prone to using maladaptive metacognitive processes, at least according to their self-report.

6.1.4 Chapter 5: A case-control study on change blindness and metacognition in depression and anxiety disorders

To further examine the change blindness effect, I ran a pilot online case-control study on age-matched samples of healthy controls and patients meeting criteria for depression and/or generalised anxiety disorder. I found no difference in performance on the change blindness task between patients and controls although the small sample size of this study only provided enough statistical power to exclude a large effect size. In this clinical study, I also included a metacognition task to further investigate the association between metacognition and depression/anxiety found in my previous exploratory analyses. Specifically, I sought to test 1) whether there is a difference in metacognitive efficiency (i.e., the extent to which subjective confidence in accuracy tracks objective performance on the task) between the patient and control groups, and 2) whether metacognitive efficiency can be voluntarily improved through instruction. I found no effects of metacognition but, again, this was a pilot study with a small sample size.

6. 2 Implications and directions for future research

In this section I first lay out the implications of my findings relating to change blindness and metacognition. I then discuss the potential advantages of integrating cognitive tasks with cognitive behavioural therapy. Finally, I make a case for the importance of further research about the impact of age on psychological treatments for depression and anxiety.

6.2.1 Change blindness

The association between depression and anxiety symptoms and a faster identification of changes in the environment may be due to hypervigilance, i.e., a heightened tendency to scan the environment for potential threats, which is characteristic of anxiety (Bar-Haim et al., 2007; Roy et al., 2008). Previous research suggests that a better ability to detect changes in the visual environment is associated with 1) less distractibility, and 2) more robust visual representations, which enable the increased detection of mismatches between the existing visual representation and incoming signal (Andermane et al., 2019). Taken together, hypervigilance, less distractibility and stronger visual representations may all be interrelated processes associated with depressive and anxious symptoms. If correct, this is a potential target for either diagnostic tools or personalised treatment. Specifically, cognitive tasks measuring change blindness altogether or its suspected component processes of hypervigilance, distractibility and strength of visual representations could be used as screening tools for depression and anxiety, alongside currently used self-reported questionnaires. In addition, it is possible that measuring these cognitive processes could help us better identify patients who are likely to respond to cognitive behavioural therapy. As mentioned in the previous chapters, it might be the case that patients with an increased ability to direct attention to previously unnoticed

changes in the environment have a higher chance of benefitting from CBT, which involves encouraging patients to take notice of internal and external events (e.g., their own automatic thoughts in response to situations, other people's reactions to them at a social gathering etc.) that usually lie outside of conscious awareness.

However, the change blindness effect was not robust to controlling for age. It was also not observed in the age-matched sample recruited in the case-control study although that adds little information given that it was a pilot study with a sample size that can only rule out large effects. Therefore, this effect may be partially or entirely explained by age. If so, this suggests that older individuals may perform more poorly on the change blindness task due to general cognitive slowing as a result of aging. However, it is also important to note that mood and anxiety symptoms and age are correlated. There is a literature demonstrating reduced depressive and anxious symptoms with age (Byers et al., 2010), and also evidence indicating that late life mood disorders might be different from those experienced in early life (Burke & Wengel, 2003). This is to say that it is hard to disentangle causality and the separable roles of age and symptoms. As an example, it is possible that older individuals are slower at the change blindness task not (solely) due to an effect of aging but because of reduced hypervigilance, which in turn makes them less likely to be depressed and anxious. Future studies could further investigate this by, for instance, measuring performance on the change blindness task in different age groups with matched depression and anxiety symptoms.

In the introduction, I proposed the theory that increased change blindness (i.e., a worse ability to notice changes) may be related to stronger predictions about the state of the world and a reduced ability to update these models (i.e., priors) in response to prediction errors based on incoming sensory data. It is possible that increased change blindness is

related to worse outcomes during CBT, which requires that patients attend to previously unnoticed features of the external environment and their internal thoughts and bodily feelings as well as that they monitor and notice changes in their symptoms in response to treatment components. Increased change blindness in older adults relative to younger adults could, therefore, lead to worse CBT outcomes in older adults. This is consistent with a meta-analysis suggesting that CBT for generalised anxiety disorder may be less effective in older adults than in working age adults (Kishita, & Laidlaw, 2017). However, a meta-analysis on CBT for depression found no difference in outcomes in younger versus older adults (Werson et al., 2022). Future research could investigate whether an increased change blindness (operationalised as longer mean reaction time in the change blindness task) predicts worse CBT outcomes.

If, as it has been theorised in this thesis, change blindness is a measure of the relative strength one places on top-down predictive models of the world vs bottom-up prediction errors based on incoming sensory data, a difference in change blindness could be associated with depression and anxiety in several ways. Future research should first disambiguate the relationship between change blindness, depression/anxiety disorders and age by testing the change blindness effect in samples matched for age and/or symptom severity. If these studies find an effect of reduced change blindness in depressed and/or anxious individuals, independent of an age effect, the causal relationship between change blindness and emotional disorders should be tested. It is possible that people with reduced change blindness (i.e., those who are more likely to notice changes in their environment) hold weaker predictive models of the world and put a greater weight on incoming sensory information. This could lead them to perceive the world as more volatile and dangerous as well as feelings of low confidence, resulting in a higher likelihood of developing depression and anxiety. It is also possible,

however, that depression and anxiety lead to weaker predictive models of the world and a stronger emphasis on prediction errors from incoming sensory information, possibly due to hypervigilance and beliefs about the world being dangerous and hostile. In this case, reduced change blindness would be a consequence of these disorders. Future studies could test the causal relationship between change blindness and trait anxiety/ anxiety disorders as well as depressive symptoms by conducting longitudinal cohort studies tracking change blindness and anxiety/depression (as well as, ideally, distinct symptoms of these conditions) over a person's development from childhood into adulthood.

6.2.2 Metacognition

In my exploratory analyses I found that older participant were less likely to engage in maladaptive metacognitive processes that are associated with higher levels of depression and anxiety. It is possible that metacognitive processes underlying these disorders improve with age, either through learning or developmental processes. It makes intuitive sense that older people may have learnt through experience to avoid counterproductive metacognitive strategies, such as believing that worrying helps them solve problems or a proclivity to monitor their own thoughts excessively. In the unscreened online samples of my studies, the relationship between age and more adaptive metacognition was stronger than the relationship between age and reduced depression and anxiety symptoms. One, highly speculative, interpretation of this finding is that improved metacognition as a result of aging plays a role – but only a partial one – in reducing symptoms of depression and anxiety over people's lifetime. Specifically, it is possible that, unlike most other cognitive processes which show a general decline with age, metacognition (at least the specific metacognitive processes that have been identified as

relevant to emotional disorders) improves with age either as a result of experience or of certain developmental processes, such as reduced impulsivity in choosing metacognitive strategies when confronting problems. It could be that a reduced tendency to engage in maladaptive metacognitive processes lessens symptoms of depression and anxiety, which is why a negative correlation between depression and anxiety disorders and age has been observed (Byers et al., 2010). If true, data showing that depression and anxiety symptoms do not diminish at the same rate during the course of aging as maladaptive metacognition does suggests that 1) engaging in unhelpful metacognition is not the sole maintaining factor of mood and anxiety disorders, 2) treatments for these disorders need to do more than just improve metacognition. However, another interpretation of the findings could be that older individuals have better metacognition as a result of a combination of life experience *and* reduced symptoms of depression and anxiety. Future research is needed to disentangle the relationship between depression and anxiety symptoms, metacognition and age by, for example, longitudinal studies measuring symptoms and cognition at various time points over the course of years. This could inform us about the directions in which depression and anxiety, metacognition and age influence each other.

Differences in metacognitive characteristics across age groups could have implications for psychotherapeutic outcomes, especially given that there is a strong possibility that metacognitive changes are an important underlying mechanism of psychological therapies (Wells, 2000). For example, if CBT exerts its effect mainly through helping patients use their metacognitive insight to understand their own cognitive biases, it is possible that older individuals respond better to such treatment, as a result of being able to capitalise on their already strong metacognition. Conversely, it is also possible that younger individuals, who are more in need of improving their metacognition, are more

likely to benefit from CBT. If the latter is true, it would suggest that patients are able to voluntarily improve their metacognition as a result of following therapist instructions. To take a first step at testing this idea, in my third study I aimed to explore, for the first time, whether metacognitive insight can be voluntarily improved through effort. I failed to find this effect in my pilot study. Specifically, in neither the patient nor control group did I find improved metacognitive efficiency (i.e., the extent to which participants' subjective confidence rating tracks their objective performance on a task) as a result of briefly explaining the important role of metacognition in depression and anxiety disorders and asking participants to try even harder to assess their own performance. If this null effect is true, it may be that it is not actually possible to shift metacognitive insight, at least over such a short time scale and with such simple instructions. However, it is also worth noting that this null finding could be due to the fact that I did not have enough power to detect a small effect size, nor did I have a way of measuring compliance with the instructions (i.e., whether participants tried harder to rate their confidence accurately after additional instruction). It could have interesting implications for psychotherapy whether or not metacognition can be improved through voluntary effort, i.e., simply through a conscious decision without altering other aspects of a person's external or internal environment. If better metacognition can be achieved voluntarily, psychological therapies should put a greater emphasis on how engagingly and convincingly instructions are delivered according to individual's needs. If, however, people cannot improve their metacognition through voluntary effort only, further research and its clinical implementations should focus on investigating the specific circumstances (outside of voluntary effort) under which metacognition improves. For example, it could be the case that people are able to improve their metacognitive insight if they facilitate objectivity by shifting their perspective from first person (e.g., "How do

you rate your confidence in your answer?") to third person (e.g., "How do you think others would rate your confidence in your answer?").

6.2.3 Cognitive tasks

The most widely accepted theoretical models of mood and anxiety disorders used in clinical practice are cognitive models (Beck, 1979; Beck et al., 2005). They propose that cognitive biases contribute to the development and/or maintenance of these psychological disorders. Cognitive behavioural therapy, which has the most evidential support among current psychological therapies, is thought to exert its effect through helping patients gain insight into and modify their cognitive biases.

There is evidence suggesting that the effect of CBT on symptoms might be partly explained by modifying cognitive biases. For instance, data on individuals with panic disorder shows a change in implicit associations and attentional bias over the course of CBT, and this change was also an early marker for good treatment outcome (Reinecke et al., 2013, Teachman et al., 2008). However, there is still little research on changes in biases outside of anxiety disorders. Likewise, more studies are needed on the effect of CBT on memory and interpretation biases. Outside of CBT, studies in the cognitive modification bias field have shown support for the success of negative affective attentional bias modification in emotional disorders by delivering computerised/smartphone interventions using cognitive tasks that train individuals to direct attention away from negative stimuli (Chelliah, & Robinson, 2022; Koster et al., 2009)

Despite the proposed cognitive underpinnings, the diagnosis of depression and anxiety as well as the tracking of changes in symptoms during the course of psychotherapy are predominantly done by self-reported symptom measures. Little empirical work has been

done on identifying the cognitive biases observed in depression and anxiety through cognitive tasks, which could provide more precise and objective measures of cognition. Moreover, there is paucity of research on what type of changes in more empirically defined cognition occur over the course of cognitive behavioural therapy. For example, it is possible that cognitive behavioural therapy works by reducing patients' bias toward processing negatively valenced information. It is also possible, however, that improvement in symptoms occurs by applying more effective metacognitive strategies when evaluating negative thoughts, without changing the existing negative bias per se. Cognitive tasks could potentially be used to discern the specific cognitive processes that are affected by psychotherapy and inform the development of more effective therapies, personalised treatments and the targeting of cognitive behavioural therapy to those who are most likely to benefit from it. As an example, as briefly mentioned above, it is possible that the change blindness task provides a behavioural signature of an individual's ability to bring previously unnoticed features of the external or internal environment into conscious awareness. It could be the case that those individuals who perform well on this task are likely to benefit from the cognitive components of CBT, which require that they direct their attention to new information, e.g., testing their unhelpful beliefs by observing what happens during behavioural experiments, noticing their automatic negative thoughts in response to various events, etc. Conversely, it is possible that people who perform poorly on the change blindness task are more likely to respond to the purely behavioural components of CBT, such as behavioural activation (during which they are asked to increase the number of meaningful activities they engage in (Uphoff et al., 2019)) or graded exposure therapy (during which they gradually confront feared situations (Abramowitz et al., 2019)). To test this, future studies could, for example, examine whether performance on the change blindness task

is associated with different levels of change in symptoms in response to specific therapy components over the course of CBT. We know from research that CBT is only effective in about 40-50% of individuals (NHS Digital, 2019), so novel strategies that can improve the hit rate, such as the use of cognitive tasks, are sorely needed.

In my studies I have shown that it is possible to explore the relationship between depression and anxiety and performance on cognitive tasks in large online samples, including clinical populations. However, we currently have little understanding about how closely the cognitive processes measured by contemporary tasks map onto cognitive processes identified in clinical practice as relevant to mood and anxiety disorders and measured by self-reported measures. Future research should focus on identifying and developing cognitive tasks more closely related to symptoms observed in clinical settings. As an example, in my first study, I included the negative affective priming task to test whether participants with higher depression and anxiety scores are worse at ignoring irrelevant negative information, which could be related to a tendency to ruminate and worry. One explanation for failing to find an association between task performance and depression and anxiety symptoms may be that the underlying mechanism of rumination and worry has to do with the ability to voluntarily suppress negative information, rather than ignoring it, which could be tested using existing paradigms, such as the "think/no-think" task (Dieler et al., 2014). Alternatively, rumination and worry may be more closely related to metacognitive beliefs or strategies. However, existing cognitive tasks measure only a very narrow aspect of metacognition and future studies should attempt to develop a wider range of clinically relevant metacognition tasks. An example of a starting point for this is a task developed by Rouault et al. (2022), which investigates the formation of subjective judgement about performance in individuals with high and low self-esteem, in contexts with and without

explicit feedback about their performance. This study found that lower self-esteem was associated with lower subjective estimates of one's performance. There was no effect of absence or presence of feedback received, which could potentially indicate stable/rigid reflections on one's performance.

In addition to the possibility of using cognitive tasks to refine our understanding of clinically relevant cognition underlying depression and anxiety, future cognitive tasks could possibly be integrated with clinical practice as therapeutic tools. For example, they could be used as more objective, convincing and engaging means to increase patients' insight into their own cognitive biases, in addition to relying on their subjective reflection and feedback received from therapists. To this end, future research should focus on the development of engaging cognitive tasks by making them, for instance, gamified or closely resemble real life situations. There are multiple research initiatives in progress attempting to augment online CBT through gamified tasks (Christie et al., 2019; Sriwatanathamma et al., 2023). One study found good acceptability, usefulness, and engagement during gamified CBT in anxious children (Pramana et al., 2018).

Finally, cognitive tasks measuring mental processes relevant to therapy outcomes could be invaluable means to scale up the provision of psychological treatment, especially online. It is possible that in the future individuals will be able to complete cognitive tasks to receive a diagnosis, be directed to relevant psychoeducational resources, or even therapy, in a cheap and efficient way. However, this undoubtedly depends on the development of more precise and clinically relevant cognitive tasks across many domains of cognition than currently exist.

With regard to the cognitive tasks studied in this thesis, future research is needed to investigate the relationship between the cognitive functions measured by the tasks and

depression/anxiety. Although I found that individuals with depression and anxiety are faster at identifying changes in the change blindness task, this relationship lacks clarity due to the fact that age is a confounder. My pilot replication case-control study looking at patients vs healthy controls was underpowered to discern the association between these variables, therefore, future research in age-matched and/or symptom-matched samples is necessary. Similarly, my pilot study involving the metacognition task measuring metacognitive efficiency as well as the influence of voluntary effort on increasing metacognitive efficiency was underpowered, which also warrants future research using this paradigm. The null results found in the reward bias and negative affective priming tasks are not definitive enough to cease research in this area, especially in light of conflicting previous findings and the fact that our data collection occurred during the COVID-19 pandemic, which may have affected the generalisability of the results.

6.2.4 The impact of age

As highlighted in the previous sections, there appears to be an effect of age on both cognitive processes as well as depression and anxiety symptoms. This could be due to various reasons. For example, it is possible that natural aging processes and/or increased life experience changes cognition in ways that make older individuals less prone to depression and anxiety. As a case in point, it could be that certain cognitive biases that make people vulnerable to emotional disorders, such as an increased attention to threat, are costly cognitive processes that decrease as a result of cognitive decline characteristic of aging. As mentioned above, it could also be that more life experience leads to better metacognitive insight and control, which helps older individuals correct their negative cognitive biases, and, in turn, reduce depressive and anxious symptoms. However, it is

also possible that negative affect decreases as a result of aging, which leads to cognitive changes, such as reduced negative bias or reduced tendency to worry.

The results of this thesis showing a negative correlation between age and depression as well as anxiety are consistent with previous research suggesting that both of these disorders are less prevalent in older adults than younger adults (Christensen et al., 1999; Gambin et al, 2021). In addition to these general findings, there is evidence that specific symptoms of depression and anxiety are impacted differently by age (Christensen et al., 1999). In the case of anxiety, older age has been found to be associated with a reduction in headaches, irritability, and worry. While depression is less common in older adults, evidence suggests that somatic symptoms of depression and feelings of hopelessness increase with age. It is important to note, however, that present diagnostic standards might not fully capture the real prevalence and characteristics of depression and anxiety in older individuals. For instance, it has been found that, compared to younger adults, older adults are less prone to express sadness or emotional symptoms (Fiske et al., 2009; Gallo et al.,1999). Also, it may be the case that symptoms linked to depression and anxiety are misconstrued as normal reactions to challenges commonly experienced in later life, like failing health, loss of loved ones, and decreased social support.

It is likely that cognitive characteristics and symptoms of depression and anxiety mutually influence each other over the course of aging. Previous research has shown that the interplay between emotion and cognition could function differently in the older adults relative to younger adults. For example, it has been found that older adults may be more susceptible to negative attentional bias and mood congruency effects (i.e., increased attention to and memory for information that matches in valence to an individual's internal state) than younger adults (Knight, & Durbin, 2015). The above

age-related findings suggests that depression and anxiety may be experienced qualitatively differently across age groups, which could warrant the development of different psychological treatments for patients stratified by age.

Given the aging population in many societies, it is increasingly important to disentangle the relationship between cognition, symptoms and age. This could be done, for example, by measuring cognitive processes in groups matched for age with differing diagnoses and vice versa. It is possible that a better understanding of the role of age in relation to cognition and emotional disorders could lead to the identification of age-based subgroups of patients who are likely to respond to different kinds of therapeutic tools.

6.3 Limitations

Although online studies have the advantage of increased sample size (and were necessary due to the COVID-19 pandemic concurrent with this PhD), an overarching limitation of my studies has to do with concerns about data quality in online samples. A lack of compliance with task instructions could result in reduced statistical power to detect true effects. Moreover, it has been shown that inattentive responding in online experiments can lead to spurious associations between symptom questionnaires and performance on cognitive tasks, generally in the direction of more severe symptoms being linked to poorer task performance (Zorowitz et al., 2021). In my studies, inattentive participants were excluded based on task performance only, indicated by implausibly short reaction times and random responding. However, previous research suggests that a potentially more effective way of screening participants is by including attention checks within symptom questionnaires (Zorowitz et al., 2021). Nevertheless, some of my results provide a certain level of assurance that participants in my studies, on the whole, complied with task instructions. In my first study, although I did not find

the predicted association between depression and anxiety symptoms and performance on the reward bias and negative affective priming tasks, I did find the overall reward bias and priming effects observed in previous studies. This suggests that (at least a large proportion of the) participants completed the tasks attentively.

The fact that online participants are unlikely to be representative of the general population poses a further limitation with regard to the external validity of my findings. Participants recruited through Prolific, the platform I used in my first two cross-sectional studies, are more likely to be younger, female and more highly educated than the general UK population (Prolific, 2022). We also cannot be sure that they are who they say they are. This problem was reduced in the case-control study, where each participant was contacted by telephone, but does not fully eliminate it. Furthermore, participants in my studies were convenience sampled, i.e., chosen on a first-come, first-serve basis. This introduces a rapid responder bias by selecting for participants who are most readily available at the time that the experiment is launched. Furthermore, selection bias may occur when participants choose to participate in the study based on its description and financial reward. It is possible that individuals interested in the same study are systematically different from the general population.

An additional limitation of this work is that it is challenging to interpret findings across cross-sectional studies using continuous symptom scales in the general population and case-control studies selecting for the presence or absence of psychiatric diagnoses. It is not clear to what extent higher scores on continuous depression and anxiety scales select for the same symptoms as diagnostic screening tools, or if there are unique features about diagnostic ‘case-ness’. Therefore, it cannot be ruled out that discrepancy between these measures contributed to failing to find the same effects in my clinical case-control

study as I did in my previous two cross-sectional studies. In addition, generalising from my cross-sectional studies to clinical populations should be done with caution as the sample in my study was recruited from the community rather than from clinical services. This population is less likely to be medicated than those recruited from clinical services, but at the same time they may be a less severe group.

A limitation that runs through this thesis is that the online experiments designed (containing multiple cognitive tasks and questionnaires) were too long to include additional questionnaires measuring specific symptoms. This is particularly a concern given that depression and anxiety are highly heterogeneous constructs (i.e., to take an extreme case, two individuals may be diagnosed with depression without sharing any symptoms). Regarding the reward bias and negative affective priming tasks, it is possible that we failed to find a true effect meaningfully related to depression and/or anxiety because of the symptom heterogeneity of our sample. It has been shown that performance on the reward bias task is associated with anhedonia, a common but not necessary symptom of depression (Liu et al., 2015). Similarly, the negative affective priming task has been linked to ruminative tendencies (a common symptom of depression and, arguably, anxiety, in the form of worry) as measured by the Ruminative Response Scale (Goeleven et al., 2006, Parola et al., 2017). Therefore, future studies should further investigate the relationship between these tasks and specific symptoms.

In addition, the length of our experiments (approximately 45 minutes) could have driven null results due to exhaustion and/or boredom affecting performance (Tyng et al., 2017). Furthermore, the large cross-sectional studies were conducted during COVID-19 lockdowns. It is possible that this highly unusual context had an effect on mood and

anxiety symptoms in our sample in a way that was not captured by the symptom measures used. This could have also contributed to false null findings.

A further limitation of the thesis is that in my cross-sectional and clinical case-control studies I focused exclusively on 1) trait anxiety (a relatively stable characteristic of an individual, signifying one's tendency to experience anxiety in a wide range of situations (Spielberger, 1983)) and 2) anxiety disorders (specifically, generalised anxiety disorder with or without other co-morbid anxiety disorders). However, the investigation of another form of anxiety, state anxiety, could further our understanding of the relationship between depression/anxiety, cognitive biases, and CBT. State anxiety is a transient experience in response to an immediate perceived threat (Spielberger, 1983). For example, a person might experience state anxiety before giving a public speech or going on a first date. Evidence suggests common as well as distinct neurological underpinnings of state and trait anxiety (Saviola et al., 2020). It is possible that there is a differential effect of state anxiety on cognition among individuals with varying levels of trait anxiety/depression (or specific symptoms of these conditions). This could provide useful insights into therapeutic approaches by informing us about how an individual's cognition changes during stressful situations, both during a therapeutic intervention and outside of it. For instance, if a person exhibits a reduced sensitivity to reward measured by the reward bias task, when experiencing state anxiety, certain CBT interventions, such as the successful completion of a behavioural experiment with positive results, may be less effective

Finally, my clinical study presented in Chapter 5 was a pilot study, with only 20 patients and 20 healthy controls. As a result, I likely lacked statistical power to detect effects in the range normally observed in clinical samples.

6.4 Conclusion

Integrating cognitive tasks with clinical practice could be a promising way of 1) understanding more about the cognitive processes underlying depression and anxiety, 2) identifying the specific cognitive mechanisms through which psychotherapies exert their effect, 3) developing more effective, engaging and personalised treatments, and 4) scaling up the provision of psychological therapies. As an early step in bridging the gap between contemporary cognitive testing and the treatment of depression and anxiety in clinical settings, I investigated the association between performance on cognitive tasks and depression and anxiety in the general population as well as in a clinical sample. I found preliminary evidence that more severe symptoms of depression and anxiety may be associated with a better ability to detect changes in the environment, which could point to potential attentional mechanisms relevant to these disorders. However, this finding should be interpreted with caution as it may be confounded by age and, in any case, my study designs are not optimised for causal inferences. Moreover, in my pilot study, there was no evidence of an association between depression and anxiety diagnoses and metacognition, nor did I find that metacognitive insight could be improved through voluntary effort as a result of CBT-like instruction. Future research should further investigate the putative change blindness and metacognition effects whilst controlling for age and, more generally, develop cognitive tasks that measure clinically relevant cognition in depression and anxiety and integrate them with cognitive interventions.

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