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Cognitive processes predict worry and anxiety under different stressful situations

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ABSTRACT

Worry, a stream of negative thoughts about the future, is maintained by poor attentional control, and the tendency to attend to negative information (attention bias) and interpret ambiguity negatively (interpretation bias). Memories that integrate negative interpretations (interpretation-memory) may also contribute to worry, but this remains unexplored. We aimed to investigate how these cognitive processes are associated with worry and anxiety cross-sectionally (Phase 1), and then explore which cognitive processes from Phase 1 would predict worry and anxiety during times of high stress, namely prior to examinations (Phase 2), and after the initial onset of the COVID-19 pandemic (Phase 3). Worry, anxiety, and cognitive processes were assessed in an undergraduate sample (N = 64). We found that whilst greater benign interpretation bias and benign interpretation-memory bias were associated with lower levels of concurrent worry and anxiety, only interpretation bias explained unique variance in worry and anxiety. No cognitive predictor significantly explained unique variance in prospective worry and anxiety prior to examinations. In relation to anxiety and worry during the stress of the COVID-19 pandemic, both benign attention bias and benign interpretation-memory bias predicted decreased worry; only benign attention bias predicted decreased anxiety. Findings suggest that cognitive processes can predict changes in worry and anxiety during future stressful contexts.

1. Introduction

Worry, entertaining multiple ways things could go wrong, is a common form of repetitive negative thinking evident in both general and clinical populations. It is also the core cognitive symptom of Generalised Anxiety Disorder (GAD), which involves somatic symptoms and impacts negatively on daily functioning (American Psychiatric Association, 2013). For people who experience high levels of worry, 22% also meet the criteria of GAD (Ruscio, 2002). High worriers who do not meet criteria of GAD show less excessive and uncontrollable worry, fewer worry topics, and less distress than individuals with GAD (Hirsch, Mathews, Lequertier, Perman, & Hayes, 2013; Ruscio, 2002; Ruscio & Borkovec, 2004). Given that worry is on a continuum with GAD, the underlying mechanisms associated with worry need to be explored to identify potential factors that protect people against excessive worry.

The current study aimed to identify how different cognitive factors predict subsequent levels of worry in different stressful situations. Understanding cognitive processes underpinning worry can help identify targets for intervention and prevention programs aimed to reduce uncontrollable worry under stress. Hirsch and Mathews (2012) proposed a model of uncontrollable worry that identified key cognitive factors such as the tendency to attend to threatening information (i.e., negative attention bias), to interpret ambiguous situations negatively (i.e., negative interpretation bias), and impaired ability to shift attention from distractors (i.e., poor attention control). However, it is still unclear how interpretation bias influences the ways individuals memorise events and whether biased memory is associated with worry. It is also unclear whether cognitive biases predict levels of worry under stress. These

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research gaps were addressed in the present study.

People with high levels of trait worry have poor attention control compared to low worriers (Stefanopoulou, Hirsch, Hayes, Adlam, & Coker, 2014), especially when worrying in normal verbal form (i.e., thinking in words), compared to when instructed to worry in imagery-based form (i.e., having images and other senses in mind; Leigh & Hirsch, 2011). Furthermore, high worriers have poorer attentional control when they are worrying than when they think about a positive event (Hayes, Hirsch, & Mathews, 2008; Stefanopoulou et al., 2014). Poor attention control in worriers may impair their ability to deliberately disengage from negative information, thereby exacerbating any attention bias towards threat. Indeed, high worriers demonstrate a negative attention bias compared with low worriers (Goodwin, Eagleson, Mathews, Yiend, & Hirsch, 2017) and their negative attention bias is increased after they have worried in the normal verbal form before the attention bias assessment, compared with worrying in imagery (Williams, Mathews, & Hirsch, 2014). Furthermore, a causal role for attention bias maintaining worry was observed by Krebs, Hirsch, and Mathews (2010), who showed that enhancing attention to threat words (via training) increased negative thought intrusions (a behavioural index of state worry) in the general population, and training high worriers to attend to benign content (i.e., positive or neutral words) reduced negative thought intrusions (Hayes, Hirsch, & Mathews, 2010). While some studies (e.g., Beckwé & Deroost, 2016; Engels et al., 2007; Sass et al., 2010) found no negative attentional bias among high compared to low worriers, these null-findings may be explained by the absence of a verbal worry induction before the attention bias task (see Williams et al., 2014). It is likely that activated worry restricts attentional control capacity (Hayes et al., 2008), making it harder to disengage from negative information. Therefore, attention bias may operate in non-clinical high worriers in particular if state worry has been activated.

In contrast to the mixed findings for attention bias, evidence consistently shows that interpretation bias maintains worry. Interpretations can be generated at different stages of information processing: “online”, when individuals make immediate interpretations, to “offline”, when individuals generate them on reflection, thus requiring time to disambiguate the information (Hirsch, Meeten, Krahé, & Reeder, 2016). Initial studies (Krahé, Whyte, Bridge, Loizou, & Hirsch, 2019; Suarez & Bell-Dolan, 2001) show that negative offline interpretations are associated with greater trait worry. Feng et al. (2019) established that low worriers tend to interpret ambiguity in a benign manner (i.e., benign interpretation bias, including both positive and neutral interpretations) across both offline and online stages of processing when state worry was activated. However, high worriers did not show any interpretation bias, i.e., they lacked the positive interpretation bias evident in low worriers.

Most of the cross-sectional studies on cognitive biases do not investigate them in the context of stressful situations. A few, however, have examined cognitive processes in stressful circumstances. For example, Vălenaş et al. (2017) examined attention bias under examination stress and found that negative attention bias was related with increased state anxiety on the day of examinations. Moreover, the relationship between rumination two weeks before the exams and exam state anxiety was mediated by attention bias. Studies also showed that cognitive processes influenced reactivity to induced stress. Participants who were experimentally trained to generate benign interpretations experienced less stress reactivity during a stress task (Mackintosh, Mathews, Eckstein, & Hoppitt, 2013), and improved recovery from stress as evidenced by heart rate measurement (Van Bockstaele, Clarke, Notebaert, MacLeod, & Salemink, 2020) compared with participants experimentally trained to generate negative interpretations. These results indicate that cognitive processes interact with stress. It is likely that these cognitive processes may also serve as predictors for later worry and anxiety under stress.

In related fields, a limited number of prospective studies have focused on the predictive nature of cognitive processes in future depression and anxiety (depression: Everaert, Duyck, & Koster, 2015; Johnson, Joormann, & Gotlib, 2007; depression and anxiety: Ho, Dai, Mak, & Liu, 2018), but not worry specifically. Furthermore, few studies have examined whether cognitive processes predict emotional symptoms during stressors. Initial prospective research by Kleim, Thörn, and Ehlert (2014) investigated whether medical students' interpretation bias before their internship predicted depressive symptoms during the internship. Students with greater benign interpretation bias before the internship had fewer depression symptoms at sixth months into the internship, even when controlling for initial depression levels. Quinn and Joormann (2015) investigated whether attention control during the semester predicted future depressive symptoms at the end of semester in a student sample. Post-experimental-stressor attention control predicted subsequent depressive symptoms when controlling for baseline depressive symptoms and pre-stress attention control. These studies focused on depression, but whether benign interpretation bias and/or high levels of attention control predict later worry and anxiety, which involves more somatic symptoms, when people encounter stress has not been investigated. It is also unclear whether other cognitive processes (e.g., attention and memory) predict worry and anxiety under stressful events.

In contrast to research on attention control, attention and interpretation biases, there is little evidence that memory bias plays a role in maintaining worry or GAD. Memory bias refers to the tendency to recall more explicitly negative than benign information. Eight studies failed to identify a memory bias related to trait worry or GAD (e.g., Mogg, Mathews, & Weinman, 1987; for a review, see Coles & Heimberg, 2002), while only three studies have found relationships between negative memory bias and trait worry (McKay, 2005) and GAD (Bradley, Mogg, & Williams, 1995; Friedman, Thayer, & Borkovec, 2000). These studies typically assessed how many valenced words individuals recalled from a previous task, but did not consider the influence of other cognitive processes (e.g., attention and interpretation) influencing encoding or retrieval of information. According to the “combined cognitive biases hypothesis” (Hirsch, Clark, & Mathews, 2006), cognitive biases can influence each other or interact to maintain psychological dysfunction. This idea is supported by a study showing that negative attention bias was linked with more negative interpretation bias; negative interpretation bias, in turn, was linked with more negative memory bias, and these biases correlated with increased depression (Everaert, Duyck, & Koster, 2014). The notion that memory bias can be influenced by interpretational processes was proposed by Hertel, Brozovich, Joormann, and Gotlib (2008) who examined this idea in the context of social anxiety. Individuals with high social anxiety interpreted ambiguous events more negatively, and integrated more negative interpretations into memory when recalling the original events later, displaying a negative “interpretation-memory bias”. To date, no study has investigated the relationship between interpretation-memory bias and worry, and this was investigated in the current study for the first time.

The current study examined multiple cognitive processes (attention bias, interpretation bias, attentional control) and the combined interpretation-memory bias in association with worry and anxiety (Phase 1, cross-sectional data). Furthermore, the current research explored which cognitive processes, assessed at baseline, would predict future levels of worry and anxiety when the same group of participants were about to take exams (Phase 2, predicting exam worry and anxiety), and under the impact of the COVID-19 pandemic (Phase 3, predicting COVID-19 worry and anxiety). This study helps to identify which cognitive processes predict worry and anxiety when individuals are facing different stressors, thereby enhancing our understanding of the cognitive mechanisms of worry and anxiety.

2. Phase 1: cross-sectional data

The aim of this part of the study was to understand whether different cognitive processes are associated with worry during a stressful life phase of transitioning to university, using a cross-sectional design. Cross-sectional studies have addressed related issues by exploring whether different cognitive processes are associated with symptoms like anxiety and depression, and provide unique variance in explaining symptoms (e.g., anxiety and depression: Klein, de Voogd, Wiers, & Salemink, 2018; Smith, Reynolds, Orchard, Whalley, & Chan, 2018; depression only: Orchard & Reynolds, 2018). Notably, no study has taken this approach with worry. The approach here was to assess multiple cognitive processes at the same lab session to investigate whether some cognitive processes explain independent variance and play more important roles than others, thereby informing our understanding of the mechanisms associated with worry. The current study specifically considered the combined cognitive bias approach and explored how memory is influenced by interpretations, and the extent to which interpretation-memory is associated with worry.

Given that worry is the cognitive component of anxiety, the current study also measured anxiety at the same time as worry. This helped us understand whether worry has unique cognitive processes associated with it, or whether the same processes can predict both worry and anxiety. Based on previous literature, we hypothesised that benign information processing biases (attention, interpretation, and interpretation-memory) and higher levels of attention control would be associated with lower levels of worry and anxiety.

2.1. Methods

2.1.1. Design

This cross-sectional study aimed to investigate how multiple cognitive biases are associated with worry and anxiety, especially when individuals are under the stress of starting undergraduate study. Starting university is a transition phase when students encounter new academic, social, and personal stress (Boujut & Bruchon-Schweitzer, 2009). First-year undergraduate students with varying worry levels took part in the study within the first 10 weeks of their enrolment into university. All participants completed self-report questionnaires to assess the extent of worry, anxiety, and depression. Attention bias, offline and online interpretation bias, interpretation-memory bias, and attention control were measured using computerised tasks.[2] A period of worry was experimentally induced before the attention, online interpretation, and attention control assessment tasks, which has been shown in earlier research to be necessary in order to identify cognitive biases in non-clinical populations. The study (Phase 1, 2, and 3) was approved by King's College London Research Ethics Committee.

2.1.2. Participants

Participants were recruited through online advertisements at King's College London and Facebook pages of other universities in London in Oct–Dec 2018. First-year undergraduates aged between 18 and 24 years old were invited to take part. Participants were excluded if they were not fluent in English, had current psychotherapy or counselling, or had poor vision. Based on these criteria, 64 first-year undergraduate participants were included in this study. Fifty-three participants (82.81%) were female and mean age was 19.19 years (SD = 1.11; range: 18–23). Thirty-two participants self-reported as Caucasian or white (50%), 24 participants as Asian (37.5%), 5 participants as British African or Black (7.81%), and 3 participants as Other ethnicity (4.69%, Sephardic/Ashkenazi, Arab, and Mixed). See Table 1 for descriptive statistics and tests, and see also "Questionnaire Scores and Participant Categorisation" in the supplementary materials.

[2] Electroencephalogram (EEG) was also recorded during the tasks, but the data is not included in this paper.

Table 1
Mean (SD; range) for sex, age (at Phase 1), and the questionnaire scores, and tests for comparisons between three phases.

	Phase 1 (n = 64)	Phase 2 (n = 55)	Phase 3 (n = 49)	Comparison between phases
Sex	82.81% female	83.64% female	81.63% female	χ^2 (2) = 0.07, p = .964
Age[a]	19.19 (1.11; 18–23)	19.13 (1.08; 18–23)	19.22 (1.12; 18–23)	F(2, 165) = 0.103, p = .902
PSWQ	54.23 (13.34; 24–80)	57.36 (11.84; 28–79)	56.10 (12.47; 27–77)	F(1.71, 70.28) = 2.85, p = .073
GAD-7	7.34 (4.79; 0–21)	8.25 (4.93; 0–19)	9.27 (5.66; 0–21)	F(1.52, 62.12) = 5.31, p = .013; post-hoc: Phase 3 > Phase 1
PHQ-9	8.78 (5.65; 0–24)	9.42 (5.83; 1–23)	9.43 (5.63; 0–23)	F(1.73, 70.93) = 2.24, p = .121

Note: PSWQ=Penn State Worry Questionnaire; GAD-7 = Generalised Anxiety Disorder 7-item scale; PHQ-9 = Patient Health Questionnaire 9-item. Greenhouse-Geisser correction for degree of freedom was applied for PSWQ, GAD-7, and PHQ-9 tests to adjust for lack of sphericity in the tests. Data for Phase 2 and Phase 3 is also presented here for ease of comparison.

[a] Given we do not have participants' birthdays, age averages across three phases were calculated using the age participants provided when they enrolled in the study (Phase 1).

2.1.3. Measures[3]

2.1.3.1. Standardised self-report questionnaires. Self-reported levels of trait worry were assessed using the Penn State Worry Questionnaire (PSWQ, Meyer, Miller, Metzger, & Borkovec, 1990). It consists of 16 items, rated on a 5-point scale from 1 (not at all typical of me) to 5 (very typical of me). The summed scores range from 16 to 80 with five reverse-scored items. A higher score indicates a higher level of trait worry. Cronbach's alpha was .94 at Phase 1. Anxiety symptoms in the past two weeks were measured using the Generalised Anxiety Disorder 7-item scale (GAD-7, Spitzer, Kroenke, Williams, & Löwe, 2006), which consists of seven items. Each item is scored from 0 (not at all) to 3 (nearly every day). The summed scores range from 0 to 21; a higher score indicates higher anxiety. Cronbach's alpha was .88 at Phase 1. Depressive symptoms in the past two weeks were measured using the Patient Health Questionnaire (PHQ-9, Kroenke, Spitzer, & Williams, 2001) for the purpose of better characterising the sample, which consisted of nine items. Each item is scored from 0 (not at all) to 3 (nearly every day). The summed scores range from 0 to 27; a higher score indicates higher depression levels. Cronbach's alpha was .87 at Phase 1.

2.1.3.2. Attention control assessment task. Emotional n-back task. The emotional n-back task (Quinn & Joormann, 2015) was adapted from the original n-back task (Kirchner, 1958) but with positively and negatively valenced words. Affective stimuli were used given that a previous study showed that attention control over affective stimuli, rather than neutral, is related to repetitive negative thoughts (e.g., Cohen, Mor, & Henik, 2015). The task included three series of 120 trails. For each trial, a word was presented for 500 ms followed by a 2500 ms interval. Participants were asked to indicate whether the word was identical to the word that was presented 1, 2, or 3 trials previously, corresponding to 1-back, 2-back, and 3-back respectively. Participants were clearly instructed which rule to follow (1- or 2- or 3-back) before each series of trials started. Before the main task, participants completed a set of practice

[3] All the bias scores in the study were calculated such that a more positive score denotes a greater benign bias.

trials to ensure they understood the task. The words presented in the 2- and 3-back conditions were those used in Quinn and Joormann (2015) .[4] Given that the latter study did not include a 1-back condition, the words presented in the 1-back condition were selected from Goodwin et al. (2017).[5] The accuracy levels for the different trial types served as an index of attention control. Higher accuracy rates represent better attention control. The split-half reliability for the accuracy based on the odd and even trials was $r = 0.91$. Please see Table 3 for the descriptive statistics.

2.1.3.3. Attention bias assessment task. Dot-probe task. The dot-probe task (MacLeod, Mathews, & Tata, 1986) included benign (either positive or neutral) and worry-related negative words that were used in Williams et al. (2014). The task included 240 trials. Each trial presented a pair of word stimuli, which were displayed at the right and left side of the fixation point, followed by an identification target (:or ..) that was displayed at the location of one of the words. Participants were asked to discriminate between the vertical and horizontal orientation of the dots as quickly and accurately as possible. Within the 240 trials, 160 of the trials included word pairs that consisted of one negative word and one benign word, the remaining 80 trials had word pairs that consisted of two benign words. The reaction time medians for the dots that replaced negative/benign words in the benign-negative word pairs were computed. An attention bias index[6,7] was computed by subtracting the reaction time median for dots replacing benign words from the reaction time median for dots replacing negative words. Thus, a higher score indicated a greater benign attention bias. See Table 4 for descriptive statistics.

Table 2
Examples of the story writing and recall task: scenarios, participants generated endings, and recalled scenarios.

Scenario	Participants generated ending	Recalled scenario
You go for an interview for a job you really want. During the interview, you answer all the interviewer's questions. As you answer, you can tell from the interviewer's reactions what your chances are of getting the job.	Your interviewer seems very pleased with your answers and their face looks as if they will give you the job. They are really friendly and say they will be in touch tomorrow (benign interpretation).	You answer all of the questions and you can tell by the interviewers' expression whether you go the job or not (no intrusion, "other" category)
	You receive an email not long after. Joy rushes to your face as you read the email, you are accepted! (benign interpretation).	You think it went well judging by the interviewer's expressions (benign intrusion).
	Annoyingly he doesn't seem to think you're right for the job. This is silly because it's your dream job (negative interpretation).	You don't think the interview is going well from the interviewer's expressions (negative intrusion).
You are at the clinic for your routine check. When you see your doctor, she asks you about your health in general, and looks at your blood test results. You see her expression changes and then she starts to speak.	They have found something strange about the results so want to have more checks (negative interpretation).	You have some blood tests. The doctor expression changes when she reads the results (no intrusion, "other" category).
	'How are my results'? says me, 'Great!' he replied (benign interpretation).	The doctor thinks that everything is perfectly fine when I asked him (benign intrusion).
	I begin to overthink all the times when I perhaps drank too much or didn't sleep enough, arguing with myself because I should take better care of myself but I also know that it is important to socialise and have fun so I shouldn't feel guilty but I do (negative interpretation).	The nurse looks at my blood test results with a worried expression (negative intrusion).

Table 3
Descriptive statistics in the emotional n-back task in Phase 1.

Indices	Descriptive statistics – mean (SD)		
	1-back	2-back	3-back
Correct trials[a]	(n = 62)	(n = 63)	(n = 63)
Benign word	55.89 (3.15)	49.57 (6.42)	38.79 (6.63)
Negative word	55.27 (3.01)	48.62 (6.83)	41.62 (7.64)
Overall	111.16 (5.34)	98.19 (12.67)	80.41 (13.63)

[a] Note: the total trials number in each condition is 120, and were divided evenly into benign and negative word type (60 for each word type).

2.1.3.4. Interpretation bias assessment tasks. ***Offline interpretation bias measure: Recognition task.*** The recognition task (Eysenck, Mogg, May, Richards, & Mathews., 1991) used in this study was based on Feng et al. (2020; Study 2). Ten worry-related ambiguous scenarios were presented, then participants completed word fragments by indicating the missing letter of the final word (e.g., wo_k) and answered comprehension questions. After participants had read all scenarios, they were presented with the title for each scenario followed by four statements in random order. Participants rated how similar each statement was to the original scenario using a four-point Likert-type scale (1 - very different in meaning to 4 - very similar in meaning). Of the four statements, two targets were benign or negative interpretations of the scenario that resolved the ambiguity. Another two foil statements, which did not

[4] The Quinn and Joormann (2015) study used a 2-back condition only, hence the authors provided us with both the 2- and 3-back materials they have used for the n-back task.

[5] Three sets of words for three conditions did not rotate around conditions in order to allow comparison of the results with Quinn and Joormann's (2015) study. The order of words in each set was pseudo-randomised because of the need of a 50% target rate. The logarithm of frequency (LogFQ) of valenced words between three sets did not differ from each other (negative word sets: $F(2,15) = 0.15$, $p = .864$; positive word sets: $F(2,15) = 1.27$, $p = .309$).

[6] Traditional attention bias index was used for consistency across the literature and because the use of dynamic attention indices (e.g., attention bias variability and trial-level bias score) has been criticised (Kruijt, Field, & Fox, 2016). Reaction time medians were used in the study because reaction time data are positively skewed and medians are less sensitive than means to the skew of distributions (Baayen & Milin, 2010).

[7] The issue of calculating reliability for reaction time indices is complex. According to Miller & Ulrich (2013), hundreds or even thousands of trials per condition may be needed to produce adequate reliability scores, especially if the mental processes involved between the task conditions are similar and the effect is not large. The trial numbers in the dot-probe task (80 per condition) and the lexical decision task (30 per condition) are far less than the required number. Therefore, no reliability scores were provided for the tasks. Previous research indicated that internal consistency for the attentional bias index ranges between 0.45 and .59 (0.45 in Bar-Haim et al., 2010; 0.53 in Enock, Hofmann, & McNally, 2014; 0.59 in Waechter & Stolz, 2015). For the lexical decision task, previous research indicated good test-retest reliability (0.87), and split-half reliability (0.99; Yap, Sibley, Balota, Ratcliff, & Rueckl, 2015).

Table 4
Descriptive statistics in four cognition bias measurements at Phase 1.

Task and Biases indices	Descriptive statistics – mean (SD)		
	Benign	Negative	Benign bias
Dot-probe task			
RT median (ms) (n = 62)	346.34 (82.71)	342.63 (80.79)	−3.71 (29.98)
Recognition task (n = 59)			
Similarity rating- Target	2.59 (0.50)	2.83 (0.50)	−0.24 (0.67)
Similarity rating- Foil	1.82 (0.49)	1.86 (0.46)	–
Lexical decision task			
RT median (ms) (n = 60)	654.27 (113.27)	692.14 (124.10)	37.88 (66.28)
Story writing and recalling task (n = 64)			
Story interpretation	32.34% (21.88%)	40.47% (24.52%)	−8.13% (42.23%)
Story recalling intrusion	6.25% (7.24%)	6.56% (8.59%)	−0.31% (10.69%)

Note. RT = reaction time. The 'benign' and 'negative' label in the dot-probe task represent words that were replaced by dots in benign-negative word pair trials.

relate to the ambiguity in the scenario, were used to assess general valence response bias[8] and make the purpose of the task more opaque. Cronbach's alphas for the ratings for positive and negative target statements were .65 and .71, respectively. A recognition test index of benign interpretation bias was computed for each participant by subtracting mean ratings for negative targets from mean ratings for benign targets (Hirsch et al., 2021). Thus, higher scores denoted greater similarity ratings to benign vs. negative targets (i.e., a more benign interpretation bias). Please see Table 4 for descriptive statistics.

Online interpretation bias measure: Lexical decision task (LDT). This task is based on Hirsch and Mathews (1997; 2000), and was adapted from Feng et al. (2020, Study 2). Participants were asked to read 90 ambiguous worry-related sentences with 60 active word trials resolving ambiguity in benign (30) or negative (30) ways on the final word of the sentence. Thirty trials were paired with non-words. Participants were asked to indicate if the letter string presented in the place of the final word of the sentence was a real word or not (a lexical decision) as quickly and accurately as possible. One third of trials was followed by comprehension questions to ensure participants read sentences carefully. The median[9] reaction times for benign or negative trial words were computed as interpretation bias indices. A benign interpretation bias index for reaction time was computed by subtracting the reaction time median for benign from that of negative trials. Thus, a higher score indicated a more benign interpretation bias. See Table 4 for descriptive statistics.

2.1.3.5. Interpretation bias and interpretation-memory bias assessment task. Story writing and recall task. The story writing and recall task (Hertel et al., 2008) contained 10 ambiguous scenarios, of which two were taken from Hertel et al. (2008) and the rest were adapted from materials used in Hirsch et al. (2018). Each scenario was presented as three sentences (see Table 2 for examples). In the first phase (story writing phase) of the task, participants were asked to imagine themselves as the central character of each scenario when reading the story and to type at least two additional sentences to finish each story. After participants finished 10 stories, they were asked to complete a short filler task (the speed of comprehension task, Baddeley, Emslie, & Nimmo-Smith, 1992). Then, in the second phase (story recalling phase) of the task, participants were cued with the first sentence of each scenario in turn and were asked to recall the original scenario. Then on a different page to differentiate it from the recollections of original scenarios, participants were asked to recall their self-generated endings. In this way, it is possible to clarify what the participant thought was in the original scenario they read and what they thought they had generated. Although participants did not deliberately recall the endings they generated when they recalled the "original scenario", the endings they generated were potentially recalled as part of the original. Participants worked through each scenario in turn. The self-generated story endings that reflected the interpretation of the scenario, and the recalled content that reflected participants' memory of the original scenario, which was potentially "contaminated" by the original interpretation (ending), that is, interpretation-memory, were coded by two raters. Please see supplementary materials for the coding and scoring procedure. Cohen's Kappa agreement for each self-generated ending (interpretation) for two raters was .75, and the recalled "original" scenario content (interpretation-memory) agreement of two raters was .70, indicating good inter-rater reliability.

Interpretation bias was computed by subtracting the percentage of negative endings (number of scenarios that had negative endings divided by ten) from the percentage of benign endings generated during the initial encoding phase. A higher score indicated a more benign interpretation bias. Interpretation-memory bias was computed by subtracting the percentage of negative intrusions (number of recalled "original" scenarios that contained a negative intrusions divided by ten) by the percentage of benign intrusions. Thus, a higher score indicated a more benign interpretation-memory bias. See Table 4 for descriptive statistics.

2.1.4. Worry phase

Before the dot-probe task, lexical decision task, and n-back task, participants were asked to worry about a current worry topic for 5 min.[10] This procedure was administered before these tasks because prior literature has shown that attention bias is more pronounced in high worriers following a worry induction (Oathes, Squillante, Ray, & Nitschke, 2010; Williams et al., 2014). Similarly, inducing worry prior to the lexical decision task showed differences between high and low worriers (Feng et al., 2019). Furthermore, attention control assessed after a stress induction predicted depressive symptoms (Quinn & Joormann, 2015), hence, given we were assessing impact on worry, a worry induction was used prior to the n-back task. The worry phase procedure activated worry processing and was based on Feng et al. (2020), adapted from Hertel, Mor, Ferrari, Hunt, and Agrawal (2014).

2.1.5. Experimental procedure

Twenty-four hours before the experimental session, a link to the online consent form, questionnaires (PSWQ, GAD-7, and PHQ-9), and recognition task were sent to participants. They were asked to complete the online questionnaires and the recognition task before they came to

[8] A two-way ANOVA was conducted on similarity ratings with Sentence type (target vs. foil) and Valence (benign vs. negative) as within-subject variables. The main effect of Sentence type was significant ($F(1.58) = 240.07$, $p < .001$), which was qualified by a significant Sentence type × Valence interaction ($F(1.58) = 8.60$, $p = .005$). The interaction showed that the differences between positive and negative statements were greater in targets than foils (positive targets vs. negative target, $p = .008$; positive foils vs. negative foils, $p = .559$).

[9] The reaction time medians were used in this study, in keeping with Feng et al. (2019) and because of the same reason that was mentioned in footnote 7.

[10] Participants had higher levels of anxiety after each worry time point (time 1: before LDT, time 2: before dot-probe task, time 3: before n-back task) than before that worry phase (time 1: $t(63) = -7.10$, $p<.001$; time 2: $t(62) = -5.16$, $p<.001$; time 3: $t(62) = -3.71$, $p<.001$). Due to one missing data point in time 2 and time 3, 63 participants were included in time 2 and 3. Levels of anxiety after three worry phases did not differ from each other ($F(2, 122) = 2.04$, $p = .134$).

the session. After participants arrived at the session, they again provided informed consent in person. Then, they completed a worry phase, followed by the LDT (measuring online interpretation bias), another worry phase, followed by the dot-probe task (measuring attention bias), and the story writing and recall task. A final worry phase was then administered followed by the emotional n-back task (measuring attention control). Participants were then debriefed and compensated for their time (£20).

2.1.6. Data preparation

All cognitive bias scores were transformed into z scores for analysis. The offline interpretation bias z scores from the recognition task and story writing and recall task were averaged to create the offline interpretation bias index[11]. The attention control index was the average z scores of 1, 2, and 3-back accuracies.[12] Collinearity diagnostics indicated no multicollinearity problem between the five cognitive processes variables (VIFs <1.63; Tolerances >0.62).

2.1.7. Analysis plan

To examine how cognitive processes were associated with worry and anxiety, a number of steps were taken. Firstly, to identify predictors for current worry and anxiety, backward-elimination regressions were conducted using the probability of *F; F*-to-enter and *F*-to-remove threshold were set as 0.05 and 0.1. Secondly, surviving variables were entered in hierarchical regression models to examine their contribution to worry and anxiety, respectively. We also examined whether sex was associated with worry and anxiety scores by using point-biserial correlation. If sex demonstrated significant correlations with worry and anxiety scores, then it was included in the following hierarchical regression models.

Each hierarchical regression model consisted of two steps to predict each dependent variable (worry and anxiety). The two steps for each model were: (1) sex; (2) attention control and cognitive biases indices (attention, online interpretation, offline interpretation, and interpretation-memory bias) surviving backward-elimination regression. Bootstrapping (1000 replications) was conducted if the residuals of the model were non-normally distributed (which was the case in the worry model). Collinearity diagnostics were conducted to examine multicollinearity for each model and no models suffered from multicollinearity problems (VIFs <1.03; Tolerances >0.98).

Given the number of statistical tests in the study, we conducted the Benjamini-Hochberg correction using a false discovery rate (5%) across three parts of the study to lower the potential of type-I error. The changes of significance for tests after Benjamini-Hochberg correction were noted in the results sections. See supplementary materials for the table that summarises results that became non-significant after correction.

2.2. Results

2.2.1. Associations

Correlations between cognitive process indices and worry and anxiety are presented in Table 5. Offline interpretation bias and interpretation-memory bias were correlated with both worry and anxiety scores. Attention bias was only correlated with anxiety but not worry. No significant associations with worry or anxiety were found in relation to online interpretation bias and attention control indices. Correlations between cognitive processes are presented in the supplementary materials.

2.2.2. Regressions

2.2.2.1. Backward-elimination regression. The offline interpretation bias index was the only variable retained through the backward-elimination regressions of worry and anxiety.

2.2.2.2. Hierarchical regression model. The relationships between sex and worry and anxiety were tested to decide whether sex needed to be controlled for in the later regression models. Results showed that sex (female = 0, male = 1) was significantly correlated with worry ($r = -0.32$; $p = .010$) but not anxiety ($r = -0.08$; $p = .548$).

Worry model. The worry model was significant overall (step 2 model: $R^2 = 0.38$, $F(2, 61) = 18.84$, $p < .001$). In step 1, sex was significantly associated with worry ($\beta = -0.32$, $p = .018$; step 1 model: $R^2 = 0.10$, $F(1, 62) = 7.12$, $p = .010$). Greater benign offline interpretation bias was significantly associated with lower levels of worry ($\beta = -0.53, p = .001, f^2 = 0.39$) and yielded a significant increase of variance of 28% ($p < .001$) when entered into the second step.

Anxiety model. The anxiety model only had offline interpretation bias as the predictor, so the result is the same as the correlation presented in Table 5.

2.3. Discussion

The study at Phase 1 examined the relationships between cognitive processes and worry and anxiety, and whether different cognitive processes are associated with worry and anxiety. State worry was induced prior to several assessments to activate worry-related processing biases. As hypothesised, individuals with greater benign offline interpretation bias and benign interpretation-memory bias showed lower levels of worry and anxiety. Greater benign attention bias was correlated with lower levels of anxiety. Inconsistent with the hypothesis, we did not find that all cognitive processes contributed unique variance in explaining worry. Attention bias and interpretation-memory bias did not survive backward-elimination regressions. Benign offline interpretation bias was the only factor that was associated with and contributed unique variance to lower levels of worry and anxiety.

The findings indicate that offline interpretation bias may play a more central role in current worry and anxiety in comparison to other well-investigated and theory-derived cognitive processes. However, it is unclear whether offline interpretation bias also plays a role in enhancing worry and anxiety when individuals are under high stress. Furthermore, it is possible that cognitive processes that did not provide unique variance in explaining worry and anxiety are still important in predicting them later, especially when individuals encounter high, more ecologically stressful situations (see e.g., De Putter & Koster, 2018). Therefore, the next step was to explore the predictive nature of cognitive factors on worry and anxiety. Thus, at Phase 2, we examined how cognitive processes predicted future worry and anxiety when participants were facing a common stressor, namely examination.

3. Phase 2: predicting examination worry and anxiety

Prospective studies that focused on anxiety and depression suggest that cognitive processes predict future anxiety and depression symptoms (e.g., Ho et al., 2018; Kleim et al., 2014). However, no prospective studies have investigated whether cognitive processes can predict future worry. Furthermore, given that most studies focused on one cognitive process at a time, it is unclear how multiple cognitive processes contribute to future worry. It is also an open question whether concurrent cognitive predictors of worry are similar to longitudinal predictors. Understanding which cognitive processes predict future emotional symptoms is essential as it can provide useful information to identify

[11] For the five participants who were excluded from the recognition task data set due to their low accuracies of the comprehension questions, the interpretation bias z scores from the story writing and recall task were used as the offline interpretation bias index.

[12] For the one participant with missing data in 1-back condition, the average z score of 2 and 3-back conditions was used.

Table 5
Correlations between cognitive process indices, worry, and anxiety at Phase 1.

	Attention bias index	Online interpretation bias index	Offline interpretation bias index	Interpretation-memory bias index	Attention control index
PSWQ	−.22	.04	−.57**	−.33**	−.07
GAD-7	−.28*	−.002	−.52**	−.37**	.09

Note. Spearman's correlations were carried out instead of Pearson's correlations if the data was not normally distributed, which was the case for GAD-7, interpretation-memory bias index, and attention control index. *Indicates significant at p < .05; ** Indicates significant at p < .01.

individuals or groups that are more likely to develop psychological symptoms or relapse from recovery, paving the way for new preventatives or interventions targeting these factors.

The present study at Phase 2 targeted a common academic stressor, examinations, among the undergraduate student population to explore the predictive nature of cognitive processes in worry. The examinations were the first major examinations for the first-year undergraduates. Again, the anxiety measure was included in the study to explore whether worry and anxiety have distinct cognitive predictors. We expected that benign information processing biases (attention, interpretation, and interpretation-memory) and good attention control would predict lower levels of worry and anxiety under examination stress.

3.1. Methods

3.1.1. Design

The present study at Phase 2 focused on the predictive power of attention control and cognitive biases at Phase 1 for future worry and anxiety levels when participants were within a few days of their examinations (Phase 2). A follow up was conducted based on data from Phase 1, when first-year undergraduate students with different worry levels took part within the first term of their enrollment into the university. All participants completed self-report questionnaires that were administered to assess the extent of worry and anxiety again at Phase 2.

3.1.2. Participants and phase 2 assessment

Of the 64 participants in Phase 1, six participants did not complete this follow-up phase. Another three participants did not have examinations and, as a consequence, were excluded from the analyses. For the remaining 55 participants, 46 participants (83.64%) were female. The baseline worry and anxiety scores from the PSWQ and GAD-7 of these 55 participants did not differ from the original 64 participants (*ps* > .631). On average 3.53 days before the examinations (*SD* = 2.40; range: 0–17 days), the PSWQ and GAD-7 were completed again to assess the extent of worry and anxiety. See Table 1 for participants' characteristics and descriptive data.

3.1.3. Procedure

Participants were invited to complete the follow-up questionnaires (on average 61.64 days after Phase 1 assessment, *SD* = 19.38) before their examinations. Four days before the examination week, a link to the online consent form and questionnaires (PSWQ and GAD-7) were sent to participants. They were asked to complete the online questionnaires before the first day of examinations. After they completed the questionnaires, participants were debriefed and compensated for their time (£15).

3.1.4. Analytic plan

As in Phase 1, backward-elimination regressions were conducted to identify potential predictors for Phase 2 worry and anxiety. The impact of sex on Phase 2 worry and anxiety was also examined by point-biserial correlation and was included in the hierarchical regression models if it was correlated with Phase 2 worry and anxiety. Each hierarchical regression model consisted of two steps to predict Phase 2 worry and anxiety. The two steps for each model were: (1) sex, Phase 1 worry/anxiety, number of days between Phase 1 and 2, and number of days before the examination; (2) attention control and cognitive biases (attention, online interpretation, offline interpretation, and interpretation-memory bias) surviving backward-elimination regression. Given the baseline assessments were completed across term, the number of days between Phase 1 and 2 assessments were included as a control variable to ensure the period between Phase 1 and 2 was not a confounding variable. The number of days before the examinations for each participant was also controlled for to avoid potential confounding of individual differences in levels of stress (see Hoorelbeke, Koster, Vanderhasselt, Callewaert, & Demeyer, 2015). The residuals in both model were normally distributed, so no bootstrapping was conducted for the regressions. Collinearity diagnostics were conducted to examine multicollinearity for both models and we found that none of the models suffered from multicollinearity problems (VIFs <1.57; Tolerances >0.63).

3.2. Phase 2 results

3.2.1. Correlations for questionnaires and sex

Point-biserial correlation results showed sex was not correlated with worry ($r = -0.22$; $p = .115$) and anxiety scores ($r = -0.14$; $p = .295$) at Phase 2. Therefore, sex was not controlled in the following hierarchical regression model.

3.2.2. Regression analyses

3.2.2.1. Backward-elimination regression. The offline interpretation bias index was the only variable retained through the backward-elimination regressions of worry and anxiety at Phase 2.

3.2.2.2. Hierarchical regression model. ***Worry model.*** The overall worry model was significant (step 2: $R^2 = 0.66$, $F(4, 50) = 23.78$, $p < .001$). PSWQ scores at Phase 1 significantly predicted worry at Phase 2 in the step one ($\beta = 0.79$, $p < .001$; step 1 model: $R^2 = 0.65$, $F(3, 51) = 31.86$, $p < .001$). Neither number of days between phase 1 and 2 ($\beta = -0.03$, $p = .688$) nor number of days before examinations ($\beta = 0.07$, $p = .400$) predicted Phase 2 worry scores. Offline interpretation bias index did not predict Phase 2 worry ($\beta = -0.07$, $p = .488$), and did not increase the explained variance for worry in step 2 ($\Delta R^2 < 0.01$, $p = .488$) when entered in the step 2.

Anxiety model. The anxiety model was significant overall (step 2: $R^2 = 0.45$, $F(4, 50) = 10.35$, $p < .001$). GAD-7 scores at Phase 1 alone significantly predicted anxiety ($\beta = 0.63$, $p < .001$; step 1: $R^2 = 0.40$, $F(3, 51) = 11.39$, $p < .001$). Number of days between Phase 1 and 2 ($\beta = 0.04$, $p = .730$) did not predict anxiety scores while number of days before examinations ($\beta = -0.24$, $p = .031$) predicted anxiety scores. The addition of offline interpretation bias index ($\beta = -0.29$, $p = .034$, critical *p*-value = .032; $f^2 = 0.05$) entered into the second step marginally significantly predicted future anxiety and yielded a marginally significant increase of variance of 5% for the model ($F(1, 50) = 4.75$, $p = .034$; critical *p*-value = .0335).

3.3. Discussion

This study examined whether cognitive processes would predict future worry and anxiety when individuals were under examination stress. Multiple cognitive processes (attention control, attention bias, interpretation bias, and interpretation-memory bias) were assessed during term time. Then, follow-up assessments of worry and anxiety were completed a few days before university examinations started. Although offline interpretation bias was highly correlated with levels of worry and anxiety at Phase 1, it did not uniquely account for variance in worry and anxiety when individuals faced examinations. The results indicate that interpretation bias may account for some variation in trait worry and anxiety, but not in worry and anxiety levels over time.

The non-significant result in worry may be due to the time frame assessed by the questionnaires. The PSWQ measures trait worry, and it may not reflect the changes of worry or the current worry status well. A worry measure that assesses worry in a specific time period may reflect current worry status better. Therefore, another worry measure that focuses on worry during the past week was utilised for the next phase.

The current results are specific to a common stressor: examination. Therefore, it is unclear whether the results would be the same when individuals are experiencing a different type of stressful event. Stress under examinations is related to performance and may be very different from other types of (more uncontrollable) stressors. The controllability of the conditions influences how anxious individuals memorise information (Large, MacLeod, Clarke, & Notebaert, 2016), and how participants allocate their attention towards threat cues (Notebaert et al., 2011). Therefore, it is possible that different cognitive processes are involved in predicting emotional distress under different stressors. In comparison to a relatively controllable stressor, such as examinations, other stressors are less controllable and could leave more room for interpretation and attentional bias to exert an influence. To explore this possibility, the third part of the study examined which cognitive processes would predict worry and anxiety during the first few months of the COVID-19 pandemic. This was designed to reveal whether cognitive predictors are the same under two very different types of stressors.

4. Phase 3: predicting COVID-19 worry and anxiety

Phase 3 of the study sought to examine which cognitive processes predicted worry and anxiety during the first few months of the COVID-19 pandemic. COVID-19 has been a stressful situation worldwide that has changed day-to-day life greatly, and people in the UK had no experience in dealing with such a pandemic. People faced many uncertainties in different aspects of life, such as health, future, finance, and coping with the emotional distress that may accompany these situations. For undergraduate students, changes in learning, lecture delivery, social life, and the impact on their degree and job opportunities are challenging (Aucejo, French, Araya, & Zafar, 2020). In this circumstance, negative cognitive biases and poor attention control ability may increase individuals' worry and anxiety.

The follow-up assessments took place during May and June of 2020. It was the time during the first lockdown (from 23rd March) in the UK when university (where the participants studied) and non-essential shops were closed. There was limited information about the virus, no vaccines or medicine, constantly changing policies, and lockdown extensions. People were required to stay at home unless it was an essential visit and maintain social distancing practices when they were out. We hypothesised that greater benign cognitive biases (attention, interpretation, and interpretation-memory) and attention control would predict lower levels of worry and anxiety during this time.

4.1. Methods

4.1.1. Design

This study at Phase 3 aimed to investigate whether cognitive biases and attention control at Phase 1 would predict future worry and anxiety when individuals were under stress of the COVID-19 pandemic. A follow-up phase was conducted based on data from the earlier Phase 1. Data collection for this phase took place in May–June 2020 during the first national lockdown in the UK.

4.1.2. Participants and phase 3 assessment

Forty-nine participants completed the follow-phase out of the 64 participants included in Phase 1. Forty participants (81.63%) were female. The baseline worry and anxiety scores from the PSWQ and GAD-7 of these 49 participants did not differ from the original 64 participants (*ps* $> .465$). During the COVID-19 pandemic assessment period, some participants were also experiencing another university examination period. Of the 49 participants, six of them did not have any examinations, 12 of them had finished the examinations, and 31 of them completing the study were currently in their examination period.[13]

In order to have a more specific and similar time frame approach across measures when assessing symptoms, the Penn State Worry Questionnaire-Past Week (PSWQ-PW, Stöber & Bittencourt, 1998) was administered to assess the extent of worry instead of the PSWQ. It consists of 15 items with a seven-point rating scale ranging from 0 (never) to 6 (almost always). The average score was 52.53 (SD = 13.92; range: 18–77). The GAD-7 was administered to assess the extent of anxiety. Descriptive data are presented in Table 1.

4.1.3. Procedure

Participants in Phase 1 who gave consent to be contacted for further studies were invited to complete the follow-up questionnaires. The assessments were conducted on average 562.90 days after Phase 1 assessment (SD = 22.94), and on average 498.16 days after Phase 2 assessments (SD = 11.62). A link to the online consent form and questionnaires (PSWQ-PW, GAD-7, and current situation survey) were sent to them with an invitation to participate. After they completed the questionnaires, participants were debriefed and compensated for their time (£15).

4.1.4. Analytic plan

Similar to Phase 1 and 2, backward-elimination regressions were conducted to identify potential predictors for Phase 3 worry and anxiety. Sex was included in the later hierarchical regression models if it was correlated with scores of worry and anxiety at Phase 3. Each hierarchical regression model consisted of two steps for Phase 3 worry and anxiety, which were (1) sex, Phase 1 worry/anxiety; (2) attention control and cognitive biases (attention, online interpretation, offline interpretation, and interpretation-memory bias) surviving backward-elimination regression. No bootstrapping was conducted for the regressions given the residuals of the model were normally distributed. Again, collinearity diagnostics were conducted to examine multicollinearity for each model and we did not find that any models suffered from multicollinearity problems (VIFs <1.23; Tolerances >0.81).

4.2. Phase 3 results

4.2.1. Correlations between questionnaire scores and sex

Point-biserial correlation results showed sex was correlated with worry ($r = -0.31$; $p = .031$) but not anxiety scores ($r = -0.192$; $p = .186$) at Phase 3. Sex was controlled for in the worry model.

[13] There was a "safety net" policy in the university that the average grades before mid-March for the academic year were set as the lowest potential score for the full-year. Hence, if exam performance was poor due to COVID pandemic stress, marks were upwardly adjusted. The levels of stress due to examinations currently and in general were self-reported by participants. For the 31 participants who completed Phase 3 study during their examinations, the current examination stress (0 = not stressed at all; 100 = extremely stressed; M = 66.90, SD = 18.60) did not differ from the examination stress in general (M = 66.22, SD = 18.70) ($t(30) = 0.26$, $p = .796$). Individuals with or without examinations (due to not having examinations or have finished the examinations) did not differ in their state worry ($t(47) = 1.59$, $p = .119$) and anxiety ($t(47) = 0.32$, $p = .748$) scores.

4.2.2. Regression

4.2.2.1. Backward-elimination regression. Both the attention bias index and interpretation-memory bias index were retained through the backward-elimination regressions of Phase 3 worry and anxiety.

4.2.2.2. Hierarchical regression model. ***Worry model.*** The worry model was significant overall (step 2: $R^2 = 0.43$, $F(4, 42) = 8.06$, $p < .001$). In step 1, Phase 1 PSWQ scores predicted Phase 3 PSWQ-PW scores significantly ($\beta = 0.42$, $p = .003$), while sex did not significantly explain variance in the model ($\beta = -0.20$, $p = .138$; step 1 model: $R^2 = 0.26$, $F(2, 44) = 7.87$, $p = .001$). Attention bias and interpretation-memory bias yielded a significant increase of variance of 17% when entered into step 2 ($F(2, 42) = 6.33$, $p = .004$). Greater benign attention bias ($\beta = -0.35$, $p = .005$, $f^2 = 0.13$) and interpretation-memory bias ($\beta = -0.29$, $p = .030$, $f^2 = 0.07$) significantly predicted independent variance in decreased worry levels at Phase 3.

Anxiety model. The overall anxiety model was significant (step 2: $R^2 = 0.27$, $F(3, 43) = 5.41$, $p = .003$). In step 1, GAD-7 scores at Phase 1 significantly predicted Phase 3 GAD-7 scores ($\beta = 0.34$, $p = .021$; step 1 model: $R^2 = 0.11$, $F(1, 45) = 5.71$, $p = .021$). Benign attention bias ($\beta = -0.32$, $p = .021$, $f^2 = 0.11$) but not interpretation-memory bias ($\beta = -0.29$, $p = .043$, critical p-value $= .035$, $f^2 = 0.08$) predicted decreased anxiety at Phase 3 when entered into step 2. The step 2 model was improved significantly by increasing 16% of variance explained ($F(2, 43) = 4.78$, $p = .013$).

4.3. Discussion

The study aimed to investigate whether cognitive processes predict state worry and anxiety during the start of the COVID-19 pandemic, when uncertainty was very high and the situation was very threatening. Undergraduate students completed worry and anxiety questionnaires during the first few months of the COVID-19 outbreak in the UK. More than half of the participants (63%) also had university examinations during data collection. The cognitive process indices from the first assessment when participants enrolled in the university were used to see whether they could predict levels of worry and anxiety during the COVID-19 pandemic. The results showed that greater benign attention bias predicted lower levels of worry and anxiety, and greater benign interpretation-memory bias predict lower levels of worry around one and half years later when COVID-19 broke out. Interestingly, these cognitive predictors explained unique variance in worry and anxiety when controlling for initial levels of worry and anxiety.

5. General discussion

The current study aimed to investigate the associations between cognitive processes and worry and anxiety. Specifically, we took an integrated approach, examining multiple cognitive factors using cross-sectional and prospective designs. The research involved two follow-up phases to examine which cognitive processes can predict changes in worry and anxiety when individuals are facing different stressors. The findings showed that worry and anxiety were associated cross-sectionally with offline interpretation bias and interpretation-memory bias. Anxiety was also associated with attention bias. Additionally, cognitive processes significantly predicted later worry and anxiety above and beyond baseline scores and other control variables. The summary results of the key predictors of worry and anxiety during baseline and the two follow-up phases are presented in Table 6. The following sections will discuss the key findings in detail.

Table 6
Summary of the significant factors in the models at the three phases.

	Phase 1: Baseline	Phase 2: Exam Stress	Phase 3: COVID-19 Stress
PSWQ[a]	Offline interpretation bias		Attention bias, Interpretation-memory bias
GAD-7	Offline interpretation bias		Attention bias

[a] Note: At Phase 3, the outcome variable for worry was PSWQ-PW (Penn State Worry Questionnaire-Past Week) instead of PSWQ.

5.1. Interpretation-memory bias in worry and anxiety

This study explored the relationship between interpretation-memory bias and worry, and looked into the predictive nature of interpretation-memory bias in relation to worry and anxiety. The study adapted the story writing and recall task developed by Hertel et al. (2008) and provides new evidence of how memory is influenced by earlier interpretations in relation to worry and anxiety. The findings showed that benign interpretation-memory bias was associated with lower levels of worry and anxiety. This is consistent with Hertel et al.'s (2008) study that found that socially anxious participants generated more negative interpretations for the scenarios and later recalled more negative intrusions that had been incorporated into the memory for the original scenarios than did the control group. The findings also extend the literature to demonstrate the predictive nature of interpretation-memory bias, specifically in relation to worry during the COVID-19 pandemic. In contrast, interpretation-memory bias did not predict anxiety. This may be because generating interpretations and recalling these interpretations are cognitive processes that are involved in worry more directly compared with anxiety that involves both worry and somatic symptoms, making interpretation-memory bias the significant predictor of the changes in worry but not anxiety.

Findings of an interpretation-memory bias are in contrast with most research on memory and anxiety, which typically fails to demonstrate memory effects in anxious populations in relation to explicitly negative information. Previous research has shown that memory bias predicts depression (Johnson et al., 2007) and resilience (Booth, Songco, Parsons, & Fox, 2020) when unambiguously negative information was processed. The current paradigm, developed by Hertel et al. (2008), assessed how interpretations of ambiguous situations were integrated into the explicit memory of the situation, that is, interpretation-memory. This paradigm, which draws on a combined cognitive bias approach to information processing, appears to have good ecological validity, since daily-life situations are often ambiguous and can be interpreted in positive or negative ways. Future research focusing on memories of interpretations may be the key to understand how memory may have a role in predicting worry and anxiety. Given there is a lack of research on how interpretation and memory biases work interactively in relation to worry, it is worth exploring whether the findings in the current study can be replicated and whether interpretation-memory bias also plays a causal role in predicting worry in GAD and in relation to other forms of repetitive negative thinking.

5.2. Offline interpretation bias in worry and anxiety

Offline interpretation bias was associated with levels of worry and anxiety at baseline. This is consistent with previous research that found offline interpretation bias was associated with worry and anxiety (e.g., Anderson et al., 2012; Feng et al., 2019). However, offline interpretation bias did not predict future worry and anxiety when individuals were under stress. This is not consistent with the studies that found offline interpretation bias predicted depression symptoms (Kleim et al., 2014; Rude, Valdez, Odom, & Ebrahimi, 2003), and panic disorder (Woud, Zhang, Becker, McNally, & Margraf, 2014). Since offline interpretation bias was marginally significant in predicting anxiety under examinations ($p = .034$, adjusted critical p-value $= .0335$), further studies could examine whether more positive offline interpretation bias predicts lower levels of anxiety when individuals are under academic stress.

5.3. Null findings of online interpretation bias, attention bias, and attention control in worry

In contrast to previous research (Feng et al., 2019; Ogniewicz, Dugas, Langlois, Gosselin, & Koerner, 2014) and our hypotheses, no association was found between online interpretation bias and worry or anxiety in either cross-sectional or prospective timeframes. Furthermore, attention bias was only associated with lower anxiety but not worry (in contrast to Goodwin et al., 2017) in the cross-sectional part of the study. These null findings could be due to the sample characteristics. In the current study, 48% of participants could be categorised as high worriers (PSWQ $\geq$ 56), while only 19% of participants could be categorised as low worriers (PSWQ $\leq$ 39), and 33% of participants had moderate levels of worry at baseline. On the contrary, previous studies with positive results regarding an association between worry and online interpretation or attention bias compared groups of high worriers and low worriers, rather than including participants irrespective of worry levels. Specifically, low worriers had a more benign attention bias than high worriers (Goodwin et al., 2017), and had a benign online interpretation bias that was lacking in high worriers (Feng et al., 2019). Hence, the biases were evident in low worriers in particular and given that there were not many low worriers in the current study, this may have contributed to a lack of findings in relation to online interpretation bias, attention bias, and levels of worry and anxiety in this study.

Alternatively, negative attention bias in non-clinical high worriers may be less robust than in individuals with high anxiety. Negative attention bias in individuals with high anxiety has been found in well over a hundred studies (for a meta-analysis, see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007), while only a few studies have looked at how attention bias is related to worry, and the results were mixed (e.g., negative results: Beckwé & Deroost, 2016; Engels et al., 2007; and Sass et al., 2010; positive results: Goodwin et al., 2017; and Williams et al., 2014).

Attentional control at baseline was not associated with worry or anxiety at any time point in the current study. This may be due to the fact that the current study investigated the relationships using a dimensional approach that included participants with different levels of worry, while previous studies (Hayes et al., 2008; Stefanopoulou et al., 2014) found poor attention control in high worriers/those with GAD vs. low worriers/general population. Another explanation is that non-clinical populations may vary greatly in their attention control capacity or attention control is not affected strongly in non-clinical populations. This point of view was supported by previous research that found large variance of self-reported attention control scores across individuals with high and low worry (Goodwin et al., 2017). Consistently, good and poor self-reported attention control were both found in high and low anxious participants (Derryberry & Reed, 2002). Similarly, the attention control reaction time index score in the high worry group (28.73 ms, SD = 27.28) in Fox, Dutton, Yates, Georgiou, and Mouchlianitis (2015)'s Study 2 was similar to the attention control score for low worriers in Fox et al. (2015)'s Study 1 (24.19 ms, SD = 25.71). This overlap between groups was also found in the current study using the number of correct trials from the n-back task as the attention control index. We found that high worriers (based on median split) had comparable correct trials with low worriers in all n-back conditions.[14] These data indicate that there is no direct link between attention control capacity and worry or anxiety. Future research is needed to investigate the role of attention control in relation to worry based on these findings.

5.4. Different cognitive predictors for worry and anxiety under different stressors

The study included two follow-ups where all participants faced the stress of examinations (Phase 2), and COVID-19 outbreak (with 63% of participants also facing the stress of examinations at that time; Phase 3). The prospective findings showed that different cognitive biases predicted worry and anxiety at two follow-ups. Offline interpretation bias marginally significantly predicted anxiety when participants faced examinations, while attention and interpretation-memory both predicted worry, and attention predicted anxiety during the COVID-19 outbreak when many participants were also preparing for their examinations. This suggests that the influence of cognitive processes may be partially determined by the unique nature of the stressors during the two follow-up phases.

It is likely that during initial lockdown, when there were abundant policy changes and media information about the virus and COVID-safe behaviours, people may have tended to seek out information more than usual. Therefore, individuals with more negative attention bias would attend to more negative information when negative and benign information was available (e.g., the rising number of cases, the lack of medical support for the disease). Perceiving more negative information then predicted higher levels of worry and anxious somatic symptoms later on during the pandemic. Given that uncertainty around much of the COVID pandemic-related information was very high, and people were adjusting to different aspects of life to cope with the pandemic, individuals may have reflected more on uncertain or unclear but potentially threatening information during that period, enabling negative interpretations to be generated and incorporated into memories. This could explain why the tendency of recalling information with negative interpretations predicted increased worry during the COVID-19 pandemic. Since interpretation-memory bias indicates how memory is influenced by the generated interpretations, the results revealed that interpretation and memory together explained unique variance in prospective worry. Indeed, offline interpretation bias and interpretation-memory bias indices are correlated (data presented in supplementary materials), suggesting that the interpretation process is the shared cognitive component of interpretation and interpretation-memory. Therefore, when the process of recalling information is important in predicting worry, interpretation-memory bias that involves both interpretation and the subsequent memory processes became the predictor that can explain more variance in worry scores.

In contrast to the COVID-19 phase results, undergraduates facing imminent examinations would have a less broad range of explicit threat-related information to attend to (since the threat is all about exams), leading to less opportunity for attention bias to predict worry and anxiety. When thinking about examinations, participants may not need to recall much information other than their performance and preparation. Again, this is very different from the pandemic phase when there was a broad range of information that individuals could reflect on. In addition, individuals can generate numerous immediate interpretations about the current examination situation instead of recalling the previous information or interpretations. Indeed, there are various opportunities for interpretation of uncertain information. For example, when individuals think about the upcoming examination, those with the tendency to interpret things negatively may constantly make negative interpretations, for example, "the exam will go badly, I will fail the examination, or I will not prepare enough for it". These negative interpretations related to examinations could be generated frequently throughout preparation and increase perceived threat and thus their levels of anxiety, but this needs further investigation as the result was marginally significant.

The study provided prospective evidence that different cognitive

[14] The number of correct trials among 120 trials in each n-back condition: 1-back, high worry (HW): 110.37 (SD = 4.93), low worry (LW): 111.81 (SD = 5.70); 2-back, HW: 99.77 (SD = 11.48), LW: 96.66 (SD = 13.73); 3-back, HW: 81.90 (SD = 11.39), LW: 78.97 (SD = 15.55). No significant differences were found between groups. This pattern was the same when the participants were split by anxiety score from the GAD-7.

processes predict worry and anxiety when individuals were under different stressors by including two follow-up phases during stressful situations for the same population. The predictive power of cognitive processes may depend on the characteristics of the stressful events that allow for the involvement of specific cognitive processes. It should be noted that 63% of participants at Phase 3 also experienced the stress of examinations, so the results may reflect the combination of pandemic stress and examination stress. In addition, it is likely that the different timings of the follow-ups influenced the results. The first follow-up took place weeks after the first assessment, while the second follow-up took place around 1.5 years following the first assessment. Given the nature of the two stressors, the sequence of the stressors could not be counterbalanced. Therefore, the results may reflect the nature of shorter and longer follow-up phases, instead of the characteristic of stressors.

5.5. Implications of the findings

The current research makes several contributions to our understanding of mechanisms that foster worry and anxiety. First, the data extends our understanding of the longitudinal relationship between cognitive processes and worry and anxiety, and how multiple cognitive processes operate in predicting anxiety and worry. The prospective data indicates different cognitive processes have an important influence on worry and anxiety elicited under different stressful contexts or different time frames. The results broadly provide support for cognitive models of worry (Davey & Meeten, 2016; Hirsch & Mathews, 2012) that assign a critical role for cognitive processes in the maintenance of worry. Interpretation-memory bias was found to be associated with subsequent worry under the pandemic stress, providing support for the combined cognitive biases hypothesis (Hirsch et al., 2006), which proposes that different cognitive biases interact and work together to impact sustaining symptoms.

The findings have clinical implications for identifying individuals at higher risk of developing severe worry or anxiety, and what cognitive processes could be targeted when developing strategies for improving mental health during stress. While the current study demonstrated the associations between cognitive processes and prospective worry and anxiety, it did not examine whether benign biases are protective in buffering against perceived stress to reduce worry and anxiety. One approach to determining whether this is the case is to modify cognitive bias and determine whether it leads to lower levels of anxiety and worry during times of high stress. For example, CBM for attention can foster less negative attention bias (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002) and reduce anxiety (e.g., Amir, Beard, Burns, & Bomyea, 2009) and worry (Sass, Evans, Xiong, Mirghassemi, & Tran, 2017). Given this, individuals with cognitive risk factors (e.g., attention bias identified in the current study) for escalating anxiety and worry could complete CBM for attention in order to prevent escalating worry and anxiety under stress. However, it should be noted that the findings for attention modifications were mixed (see review articles MacLeod & Clarke, 2015, Mogg, Waters, & Bradley, 2017; meta-analysis: Cristea, Kok, & Cuijpers, 2015, Fodor et al., 2020). Future research is needed to identify methods best suited to prevent escalating anxiety and worry during stressful periods in those with cognitive risk factors identified in the current research.

5.6. Limitations and future directions

Some limitations of the study should be noted. The small sample sizes in Phase 2 and 3, only 55 and 49 participants, respectively, due to non-completion or not having examinations (Phase 2), limited the statistical power with two or more variables in the regression models (Cohen, 1992). In addition, the majority of the participants were female. Given that female undergraduates have higher levels of worry than male undergraduates (Davey, Meeten, & Field, 2021), more females in the study may have led to a higher average level of worry than the general population in the current study. Some of the findings became non-significant when multiple comparison correction was applied and the absence of preregistration deems the current results exploratory. Future, pre-registered research could replicate the study with a larger initial sample size to account for attrition, and attempt to recruit more equal numbers of male and female participants to see whether that would yield similar results.

Additionally, we used an unselected sample so findings may not generalise to clinical populations. However, the results are still valuable as individuals who have high worry and anxiety are at higher risk of developing GAD, and the cognitive predictors here may contribute to the development of GAD. Future studies could explore whether specific cognitive processes are evident before the onset of heightened levels of worry. Another limitation to note is that Phase 3 of the study was conducted during the first few months of the COVID-19 outbreak. It is still not known whether a lack of a benign bias or even a clear negative cognitive bias (e.g., more attention to the threat of virus) could promote adaptive benefits during a pandemic (e.g., greater compliance with COVID-19 guidelines, leading to lower rates of infection) over the longer-term. Furthermore, whilst starting university, examinations, and living through a global pandemic are potential stressors (Dyson & Renk, 2006; Koudela-Hamila, Smyth, Santangelo, & Ebner-Priemer, 2020; Kujawa, Green, Compas, Dickey, & Pegg, 2020; Savage et al., 2020), individuals may experience the impact of different types of stressors differently. Hence, future studies could include self-report ratings on how stressful individuals find a given stressor and assess whether cognitive processes are associated with perceived stress.

In summary, the current study found that cognitive biases were associated with worry and anxiety. Individuals with more benign offline interpretation bias showed lower worry and anxiety at baseline. Benign attention bias was associated with anxiety at baseline and predicted lower anxiety when individuals were facing the COVID-19 outbreak. More benign attention bias and interpretation-memory biases predicted lower worry during the pandemic. The findings indicate that some negative cognitive biases are risk factors for worry and anxiety, especially when individuals are under certain types of stress. Prevention strategies for reducing potential high levels of worry and anxiety may need to account for upcoming stress.

CRediT authorship contribution statement

Ya-Chun Feng: Conceptualization, Methodology, Software, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Charlotte Krahé:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Ernst H.W. Koster:** Conceptualization, Writing – review & editing. **Jennifer Y.F. Lau:** Writing – review & editing. **Colette R. Hirsch:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The views expressed are those of the authors and not necessarily those of MQ: Transforming Mental Health, NHS, or the National Institute for Health Research (NIHR).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2022.104168.

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