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Author Contributions

L.S.H. conceptualized the study. L.S.H. and S.N.K. designed the experimental paradigm. S.N.K. programmed the task and questionnaires. L.S.H. and S.N.K. supervised data collection. S.N.K. managed the database. L.S.H. performed the analyses. All authors contributed to interpreting the findings. L.S.H. was primarily responsible for drafting and revising the manuscript. S.N.K. and M.K.C. made additional contributions to drafting and revising the manuscript. S.N.K. created the tables. M.K.C. created the figure. All authors provided comments on the final version of the manuscript.

Worry alters speed-accuracy tradeoffs but does not impair sustained attention

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Abstract

Worry has been experimentally linked to a range of cognitive consequences, including impairments in working memory, inhibition, and cognitive control. However, findings are mixed, and the effects of worry on other phenomenologically-relevant constructs, such as sustained attention, have received less attention. Potential confounds such as speed-accuracy tradeoffs have also received little attention, as have psychometric and related design considerations, and potential moderators beyond trait worry. The present study investigated the effects of experimentally-induced worry versus a neutral control condition on speed-accuracy tradeoff-corrected performance on a validated measure of sustained attention (88 participants; within-subjects). Moderation by trait worry and trait mindfulness was probed in confirmatory and exploratory analyses, respectively. Worry led to faster and less accurate responding relative to the neutral comparison condition. There was no main effect of condition or trait worry on sustained attention after accounting for speed-accuracy tradeoffs. In exploratory analyses, higher trait mindfulness was robustly related to better post-worry performance, including after controlling for trait worry, general distress, and post-neutral performance, and correction for multiple comparisons. Follow-up analyses exploring dissociable mindfulness facets found a robust relationship between present-moment attention and post-worry performance. Future research should experimentally manipulate mindfulness facets to probe causality and inform treatment development.

Worry, the central feature of generalized anxiety disorder (GAD; American Psychiatric Association [APA], 2013), is traditionally defined as a negative, verbal-linguistic thought process centered on uncertain future events (Borkovec et al., 1983). An extensive theoretical and clinical literature links worry and similar thoughts such as rumination to self-reported impairments in attentional control (Eysenck & Derakshan, 2011; Hallion et al., 2018; Hirsch & Mathews, 2012). However, experimental research has produced mixed results. Whereas some studies find theoretically-predicted adverse effects of worry (e.g., Beckwé & Deroost, 2016; Hallion et al., 2014; Stefanopoulou et al., 2014), others find no effect (e.g., Tallon et al., 2016). Findings also vary with respect to whether trait worry moderates these effects (Beckwé & Deroost, 2016).

These mixed findings may be due to several factors. From a theoretical perspective, previous work has focused on a relatively narrow set of cognitive constructs, primarily working memory and inhibition, because they are implicated in prominent models such as Attentional Control Theory (ACT; Eysenck & Derakshan, 2011). However, the cognitive theories and corresponding tasks that are favored in clinical science, including those underlying ACT, have come under scrutiny in the cognitive neuroscience and psychometric literatures (e.g., Parsons et al., 2019; Snyder et al., 2015). By contrast, sustained attention is a theoretically and neurobiologically distinct construct (Rosenberg et al., 2016) with strong phenomenological links to the cognitive challenges that worriers, especially students, face in daily life (e.g., worry intrusions that disrupt studying).

Early experimental studies focused on sustained attention specifically found more negative thought intrusions during a focused breathing task in adults with GAD versus non-GAD high worriers (Ruscio & Borkovec, 2004). More recently, a study using a novel visuospatial tracking task (Ottaviani et al., 2013) found that probe-caught instances of perseverative cognition related to slower response times, higher intrusiveness, and more efforts to inhibit thoughts. Trait worry did not moderate this relationship. Another study using the same task (Makovac et al., 2016) reported an interaction wherein perseverative thought produced slower responses (interpreted as an index of distractibility) in 19 participants with GAD, but not 19 healthy controls. Using a modified version of the validated Continuous Performance Task (Conners, 2000), Gazzellini and colleagues (2016) reported faster responding in low versus high worriers following a perseverative thought induction.

Although informative, these studies also have important limitations. Previous work in this area has tended to suffer from low statistical power, despite complex designs (e.g., N = 32 for a between-subjects design, Tallon et al., 2016; N = 60 for a 2 x 4 x 2 mixed analysis of covariance; Gazzellini et al., 2016). Other methodological limitations include pre-post (uncontrolled) designs that limit inferences about specificity (Gazzellini et al., 2016; Makovac et al., 2016; Ruscio & Borkovec, 2004) and reliance on novel tasks with unclear psychometric properties, or that have not been validated as measures of sustained attention (Makovac et al., 2016; Ottaviani et al., 2013; Ruscio & Borkovec, 2004). Single "doses" of worry that dissipate quickly have also been identified as a common and potentially important limitation (Beckwé & Deroost, 2016).

Additionally, to our knowledge, no previous studies in this area have explicitly examined or accounted for speed-accuracy tradeoffs. Speed-accuracy tradeoffs reflect the degree to which one's response strategy favors a faster and less accurate (versus slower, more accurate) response style (e.g., Seli et al., 2013). Strategy shifts influence response times and error rates, but do not reflect sustained attention *per se*. There is preliminary evidence that such tradeoffs may emerge in the context of perseverative thought (e.g., Roberts et al., 2013); as such, this possibility is important to consider.

Finally, previous studies have focused rather narrowly on trait worry when considering potential moderators of the effects of worry on cognition (Beckwé & Deroost, 2016). Trait mindfulness, a multifaceted construct involving intentional, nonjudgmental attention to present-moment experience (Baer et al., 2006; Creswell, 2017), is robustly related to perseverative thought and trait worry specifically (Thompson et al., 2019). In light of preliminary evidence of beneficial effects of mindfulness training on sustained attention (Morrison et al., 2014; but see Van Dam et al., 2018) and attentional disengagement from perseverative thought (Gu et al., 2015), efforts to clarify the relationships between mindfulness, worry, and cognition may prove fruitful.

The present study therefore examined the effects of experimentally-induced worry on a validated index of sustained attention, with special attention to possible speed-accuracy tradeoffs and moderators of interest. We hypothesized that worry would impair subsequent sustained attention, especially for those with high trait worry. Mindfulness analyses were exploratory, but we expected higher mindfulness to relate to better performance. Exploratory follow-up analyses probed differential and incremental relationships for distinct mindfulness facets. To prevent dissipation of induction effects (Beckwé & Deroost; 2016) and increase statistical power, the inductions were “refreshed” throughout the task (within-subjects; counterbalanced).

The neutral comparison condition was an auditory lexical decision task, in which participants discriminated between neutral English words versus non-words. This approach diverges from traditional unstructured neutral or positive thought conditions (e.g., Hallion et al., 2014; Stefanopoulou et al., 2014), but offers several strengths specifically tailored to the study conceptualization and design. First, although the within-subjects design and multiple counterbalanced induction periods are strengths, they also increased the risk of spillover or contamination across conditions (e.g., intrusive worry during the neutral period), which might be confounded with moderators of interest (e.g., more spillover in high worriers). Second, because verbal-linguistic activity interferes with worry (Leigh & Hirsch, 2011; Rapee, 1993), a verbal-linguistic control task was selected to promote neutrally-valenced cognition while minimizing worry spillover. Third, recent multilevel modeling studies from our group demonstrate a robust relationship between self-referential processing and subjective uncontrollability of thoughts, irrespective of thought valence (Hallion et al., 2019). These findings are consistent with a neurobiological model that we are exploring in current work, in which impaired decoupling of the frontoparietal cognitive control network and default mode network (the latter of which is heavily implicated in self-referential processing; Whitfield-Gabrieli & Ford, 2012) is a hypothesized neural mechanism by which perseverative thought persists (e.g., as in Christoff et al., 2009). If this model is accurate, high trait worry should be associated with impaired disengagement not just from negatively-valenced perseverative thought (e.g., Koster et al., 2011), but from internally-focused, self-referential cognition more generally. The auditory lexical decision task is non-self-referential and engages largely non-overlapping neural substrates involved in externally-oriented attention (Birn et al., 2006). Finally, the lexical decision task also methodologically controls for the presence of a cross-modality shift from a non-visual task to a visual task.

Method

Participants

Participants were 88 undergraduate students at a large northeastern university (excluding four participants with technical failures, two who discontinued the study, and one with an age > 3*SD* above the *M*[1]; Table 1). Participants were 18 or older, had normal or corrected-to-normal vision and hearing, and were native English speakers. Participants had no self-reported history of psychotic or bipolar disorder, epilepsy or head trauma (past six months), or current benzodiazepine or stimulant use. Participants received course credit for participating.

Materials

Experimental Apparatus

The experiment was administered on a Lenovo YOGA 900-13ISK2 Intel Core i76560U CPU 2.20 GHz laptop computer using E-Prime Professional Version 2.0 (Psychology Software Tools, 2015). Stimuli were centered and presented in black Symbol 68-point font on a light silver background.

Experimental task

Participants engaged in alternating blocks of experimentally-induced worry and a neutral comparison condition (five blocks each; counterbalanced). Each induction was immediately followed by 108 trials of a sustained attention task (see Figure 1).

Worry Induction Blocks. The worry induction followed established procedures (Hallion et al., 2014; McLaughlin et al., 2007). Participants were first given a definition and examples of worry and asked to identify current worries. During each 2-minute worry block, participants worried about their most distressing topic "*in the way that you usually worry about it, but as intensely as you can*" (see McLaughlin et al. for complete instructions) while passively viewing a fixation cross (Figure 1A).

[1]Age is independently linked to both response times (West et al., 2002) and trait worry (Basevitz et al., 2008). Findings were similar but not identical when this participant was retained with age as a covariate and are not considered further due to undue influence of this participant on the model.

Neutral Induction Blocks. During neutral blocks, participants made word/non-word determinations using a keypad. Word stimuli were selected from the Affective Norms for the English Language Database (ANEW; Bradley & Lang, 1999) for neutral valence and similarity to stimuli used in other studies (Kousta et al., 2009). Non-words were drawn from previous research (Olson et al., 2001), matched pairwise in syllables and length to word stimuli, and followed English language phonological rules, but were meaningless. Each block included 48 trials (24 each of words and non-words). Responses were collected for 2,500*ms* following stimulus onset, followed by a 750*ms* feedback screen (Figure 1B). Lexical decision data were not analyzed.

Sustained Attention to Response Task (SART; Robertson et al., 1997). The SART is a well-characterized measure of sustained attention that shows good convergent validity with self-reported attentional lapses in daily life (Robertson et al., 1997) and probe-caught off-task thought in experimental contexts (Seli, 2016; Smallwood et al., 2004). Participants respond via button-press to sequentially-presented number stimuli, but must withhold their response to an infrequent target (8 in the present study). Each block included 108 trials with 12 No-Go (non-response) trials presented in pseudo-random order with feedback. Stimulus duration was 250*ms* with a 1150*ms* response window, followed by a 900*ms* fixation cross and 750*ms* feedback (Figure 1C).

To account for speed-accuracy tradeoffs, SART performance was analyzed using a single skill index that accounts for errors and response times (Seli et al., 2013; Seli et al., 2016), computed as (No-Go accuracy/*M* Go response time), where No-Go accuracy = ([total No-Go trials – commission errors]/total No-Go trials)*100. The skill index formula precludes trial-by-trial reliability analysis, but reliability was strong when the index was calculated and compared across blocks of each type (neutral α = .81; worry α = .87). Because the actual skill index uses data from all trials of each type, actual reliability is likely higher.

State Worry Assessment. Participants rated worry severity during each preceding SART block from 0 (didn't worry at all) to 8 (worried almost constantly).

Self-Report Measures

Trait Worry. The Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990) is a 16–item self-report measure of usual worry severity with strong psychometric properties in clinical and non-clinical samples (Brown et al., 1992; Stöber, 1998). Table 1 presents internal consistency for all trait measures.

Trait Mindfulness. The Five Factor Mindfulness Scale (FFMQ; Baer et al., 2006) is a 39-item measure containing five subscales: Nonreactivity; Nonjudgement; Acting with Awareness; Describing; and Observing. The Observing subscale reliably shows poor psychometric properties in non-meditators (Baer, 2018). As recommended by Baer (2018), Observing items were therefore excluded from study conceptualization and analyses. FFMQ total score (excluding Observing) and the remaining four subscales each show good convergent and discriminant validity, internal consistency, and incremental utility in clinical and non-clinical samples (Baer, 2018).

Distress. The Depression Anxiety Stress Scale-21 item version (DASS-21; Henry & Crawford, 2005) is a widely-used measure of emotional distress with strong psychometric properties comparable to those of the 42-item DASS (Henry & Crawford, 2005). The total score was used in the present study.

Debriefing. Following the task, participants reported on their worry, adherence, and engagement during the task (see Supplemental Table 1).

Procedure

Participants completed the study individually in a private room. After providing informed consent, participants were instructed in the experimental task and completed practice blocks. After resolving any questions, participants completed the experimental task, debriefing, and self-report measures.

Analytic Plan

Paired-samples *t*-tests were computed to compare conditions (worry versus neutral) across response time, error rates, and speed-accuracy tradeoff-corrected performance (skill index). Because tradeoffs were observed, subsequent analyses used the skill index only. Pearson correlations explored zero-order relationships between trait measures and sustained attention. Moderation analyses were conducted using partial correlations and linear regression, with post-worry performance as the dependent variable and post-neutral performance included as a covariate. Including post-neutral performance as a covariate means that moderation can be tested without a traditional interaction framework, because the dependent variable represents the specific effects of worry on performance. An independent variable that accounts for significant variance is therefore considered a moderator, because the effects of worry on performance vary as a function of that independent variable (see e.g., McArdle, 2009). Where trait mindfulness findings were significant, follow-up analyses explored independent and incremental relationships of the four FFMQ subscales to performance. Missing data were handled using pairwise deletion.

Correction for Multiple Comparisons

Benjamini-Hochberg False Discovery Rate (Benjamini & Hochberg, 1995) was used to correct for multiple comparisons across analyses. This procedure involves rank-ordering *p*-values for *k* total analyses (smallest to largest) and retaining as significant only those values that are less than or equal to the largest instance of $p \leq (\text{rank}/k)*0.05$. Findings survived correction except where specified.

Power Analysis

With 88 participants, we had 80% power to detect a small effect ($d \geq .30$) in paired *t*-tests. With 83 participants or more (accounting for missing self-report data), we had 80% power to detect a small effect ($r \geq 0.22$; $f^2 = 0.10$) in the Pearson and partial correlation analyses, respectively, and small-to-medium effects ($f^2 = 0.16 – 0.17$) for each predictor in the regression and mindfulness subscale analyses.

Results

Manipulation Checks

Most participants (86%) endorsed being at least somewhat engaged with their worry during the inductions. Most participants (58%) also reported that their worry was fairly or extremely similar to their usual worry (see Supplemental Table 1).

Effects of Induced Worry on Sustained Attention

Paired *t*-test results and effect sizes are presented in Table 2. Participants reported higher state worry during post-worry versus post-neutral SART blocks. Worry produced faster but less accurate responding, consistent with a shift in response speed strategy. There was no main effect of condition on speed-accuracy tradeoff-corrected skill index.

Relationships of Trait Measures to Sustained Attention

Pearson correlations are presented in Table 3. Significant relationships for post-worry performance with distress and trait mindfulness did not survive correction. In partial correlations, post-worry performance was robustly, positively related to trait mindfulness ($r = .31$).

In a linear regression, trait mindfulness incrementally predicted post-worry performance beyond variance explained by distress, trait worry, and post-neutral performance, $\beta = .19$, $p = .012$, consistent with moderation. Neither distress nor trait worry incrementally predicted performance, both $\beta \leq .03$, $p \geq .689$ (Supplemental Table 2).

Probing Mindfulness Facets

In follow-up analyses exploring FFMQ facets separately, Acting with Awareness was related to post-worry performance before ($r = .42$) and after ($r = .27$) controlling for post-neutral performance and correcting for multiple comparisons (Supplemental Table 3). In regression analyses, no single facet incrementally predicted the effects of worry on performance (Supplemental Table 2).

Discussion

The present study investigated the impact of experimentally-induced worry on sustained attention and potential moderation by trait worry and mindfulness. We observed faster and less accurate responding following worry relative to the neutral condition, suggesting differences in speed-accuracy tradeoff strategies between conditions. Counter to hypotheses, experimentally-induced worry did *not* impair performance after accounting for those tradeoffs. This null finding is not easily explained by statistical power or psychometric concerns. Taken at face value, these findings could plausibly be interpreted as preliminary “evidence of absence” for a causal effect of worry on sustained attention. This would suggest a need to look elsewhere to explain the marked difficulty concentrating that characterizes GAD and similar disorders (Hallion et al., 2018). Theoretical models grounded in contemporary cognitive neuroscience and metacognition, along with larger samples and better-validated tasks, are needed to address this important clinical problem.

To our knowledge, the present study is the first to explicitly consider speed-accuracy tradeoffs when examining the effects of worry on cognitive performance. This gap in the literature is notable, because theoretical and clinical implications differ markedly if findings reflect changes in ability versus strategy (e.g., Seli, 2016). Beyond testing and accounting for tradeoffs, future research would benefit from explicitly characterizing these tradeoffs and their mechanisms in relation to worry and anxiety in their own right. Future research should also dissociate relative contributions of state anxiety, which has been reliably linked to enhanced response inhibition in threat-of-shock research (Grillon et al., 2016; Torrisi et al., 2016), from potential adverse consequences of distraction by worry-related thoughts.

Methodological interpretations for the null findings are also possible. One possibility is that voluntary worry induced in the lab may differ fundamentally from the involuntary (difficult-to-disengage) worry associated with GAD. However, several prominent theoretical models of GAD propose a central role for positive beliefs about worry (e.g., Newman & Llera, 2011; Wells, 2005), suggesting that worry is at least sometimes voluntarily initiated or maintained due to those positive beliefs. The persistence of worry into the SART blocks also suggests that voluntarily-initiated worry may have become involuntary and more similar to prototypically maladaptive worry during the induction period. Moreover, the present instructions have been used successfully in past studies (e.g., Hallion et al., 2014; McLaughlin et al., 2007), and most participants reported successfully worrying in their usual manner upon debriefing. Nevertheless, nearly all participants reported being at least occasionally distracted from their worry during the induction (Supplemental Table 1). Because any consequences of distraction would err toward dilution of the induction, rendering effects harder to detect, this possibility cannot account for the positive trait mindfulness findings, but similarly cannot be ruled out as an explanation for the null findings for trait and state worry.

In exploratory analyses, higher trait mindfulness was reliably related to better post-worry performance, including after controlling for general distress, trait worry, and post-neutral performance and correction for multiple comparisons. The finding of a positive association between mindfulness and performance is broadly consistent with a model in which mindfulness could buffer against adverse effects of worry on cognition. Although these findings are correlational, preliminary experimental studies supporting beneficial effects of mindfulness for cognition (Gu et al., 2015, but see Van Dam et al., 2018) and reducing perseveration (Delgado et al., 2010) are consistent with this possibility. When facets were examined separately, only Acting with Awareness, which taps present-moment attention (Baer et al., 2006), was robustly and independently related to performance. These findings are consistent with predictions from theoretical models that place present-moment attention at the center of the mindfulness construct (e.g., Baer et al., 2006; Lindsay & Creswell, 2017), and other empirical work from our group demonstrating a robust incremental relationship of present-moment attention to transdiagnostic perseverative thought (Thompson et al., 2019).

Important strengths of the present research include the use of a well-characterized sustained attention task; consideration of speed-accuracy tradeoffs; a neutral control condition that ruled out several methodological and theoretical alternative explanations; and a within-subjects, multiple-block design that both increased statistical power and prevented dissipation of the induction over time (Beckwé & Deroost, 2016). Although our use of an undergraduate sample is ecologically valid in light of the importance of sustained attention (and cognitive functioning more broadly) to successful role functioning in academic contexts, future research should recruit a more diverse sample with respect to age, education, mindfulness exposure, and other demographic and cultural characteristics that could plausibly impact results. Finally, future research should experimentally manipulate mindfulness, ideally within a multimodal design (e.g., Van Dam et al., 2018), to probe possible causal relationships and identify potentially malleable targets for intervention.

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Table 1

Sample Characteristics

Baseline Characteristics	*M*	*SD*	α	Range	%
Gender (female)	–	–	–	–	56%
Age (years)	19.11	1.25	–	18 – 24	–
Race					
Asian	–	–	–	–	6%
Black or African American	–	–	–	–	2%
White	–	–	–	–	81%
Multiracial or Other	–	–	–	–	10%
PSWQ	53.05	13.16	.93	19 – 79	–
DASS	27.76	19.41	.92	2 – 88	–
FFMQ[a]	97.84	14.72	.86	68 – 128	–
FFMQ Acting with Awareness	24.46	5.87	.86	8 – 36	–
FFMQ Non-Judging of Inner Experience	25.98	6.32	.83	12 – 38	–
FFMQ Non-Reactivity to Inner Experience	21.57	4.47	.77	10 – 32	–
FFMQ Describing	25.53	5.56	.77	12 – 36	–

Note. α = Cronbach's alpha; PSWQ = Penn State Worry Questionnaire; DASS = Depression, Anxiety, and Stress Scales – 21 item; FFMQ = Five Factor Mindfulness Questionnaire.

[a] FFMQ total was calculated without the observing subscale.

Table 2

Sustained Attention to Response Task (SART) and State Worry Descriptive Statistics

SART Variable	Post-Neutral	Post-Worry	*t*	*p*	*d*
	M (SD)	*M (SD)*			
Probe-indexed state worry	3.52 (1.80)	4.07 (1.78)	4.92	< .001	0.53
Response time	353.76 (66.06)	346.22 (72.19)	3.29	.001	0.11
Commission errors	22.11 (10.81)	23.70 (12.12)	-2.56	.012	0.14
Skill index	0.18 (.05)	0.18 (0.06)	1.23	.222	0.13

Note. Skill Index scores are calculated as No-Go accuracy / *M* Go Response Time.

Table 3

Pearson and Partial Correlations Between Task Performance (Skill Index), Distress, Trait Worry, and Trait Mindfulness

Variable	Post-neutral index	Post-worry index	DASS-21	PSWQ	FFMQ total
Post-worry index	.84**[a]	–	–	–	–
DASS-21	-.20[†]	-.24*	–	–	–
PSWQ	-.06	-.09	.49**[a]	–	–
FFMQ total	.19[†]	.33**[a]	-.53**[a]	-.39**[a]	–
Partial correlations controlling for post-neutral index					
Post-worry index	–	–	-.14	-.07	.31**[a]

Note. DASS-21 = Depression, Anxiety, and Stress Scale – 21 item version; PSWQ = Penn State Worry Questionnaire; FFMQ total = Five Factor Mindfulness Questionnaire total score, minus Observe items.

[a] Survived correction for multiple comparisons.

[†] $p < .10$. * $p < .05$. ** $p < .01$.

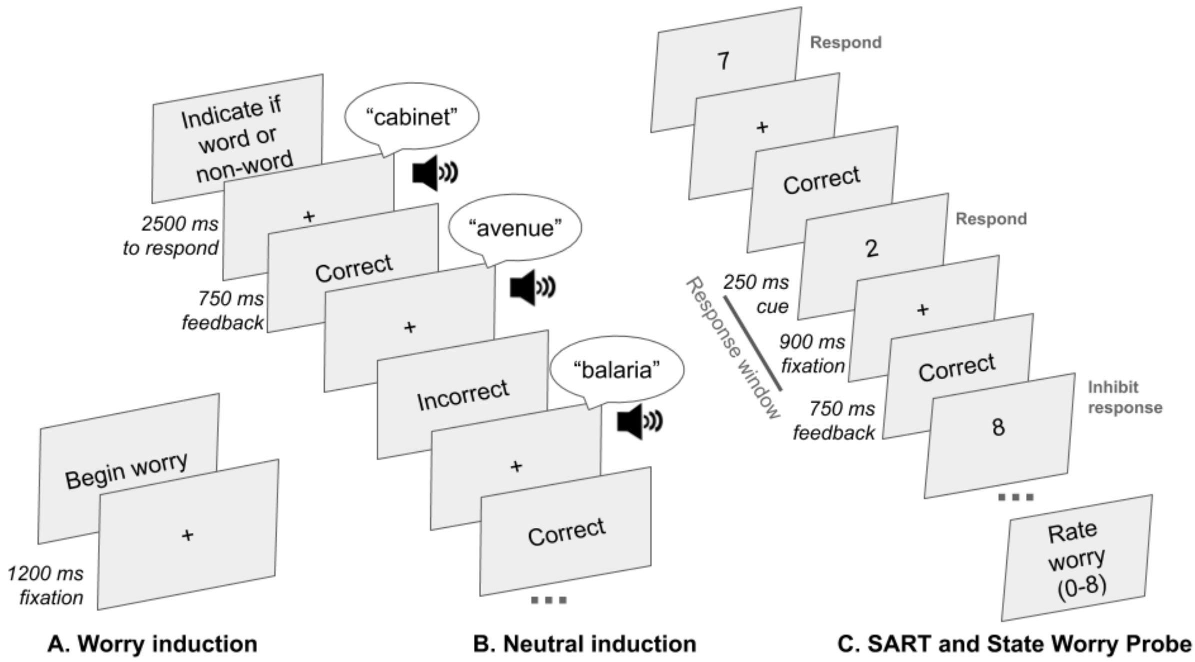

Figure 1. Overview of the experimental design.

Highlights

- We assessed sustained attention following repeated worry and neutral inductions
- Speed-accuracy tradeoff preferences differed under worry versus neutral
- Performance did not differ for worry versus neutral after accounting for tradeoffs
- Trait mindfulness but not trait worry moderated the effects of worry on performance
- Future experimental research should explore mindfulness as a protective factor

The authors declare no conflicts of interest.