The Hidden Costs of Social-Evaluative Threat: A Default Network Interference Hypothesis

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Abstract

Social-evaluative threat (SET) can impair cognitive performance, especially for individuals high in social anxiety. This impairment is likely related in part to a diversion of task-focused attention toward internal, self-focused thoughts. Socially anxious people sometimes show performance deficits even in the absence of explicit social evaluation, suggesting that minimally evaluative environments may heighten self-focus in socially anxious individuals. However, little is known about the degree to which subtler variations in social context interact with social anxiety to affect cognitive performance and, further, what neural mechanisms mediate these effects. To address this, this dissertation tests the default network interference hypothesis of SET—that SET leads to poorer cognitive performance, exacerbated by social anxiety, due to difficulty suppressing activity in a collection of brain regions related to self-focus called the default network.

Study 1 (n=61) tested a novel social context manipulation to determine whether performance on the n-back working memory task was affected by social context and whether trait levels of fear of negative evaluation (FNE) and task difficulty interacted with this. Results indicated that individuals higher in FNE showed interference via longer RTs during harder 3-back trials when under SET compared to non-SET conditions. Interestingly, SET resulted in improved accuracy during easier 2-back trials. This suggests that although ongoing SET may improve task effectiveness, efficiency is reduced, especially in socially anxious individuals during high task difficulty.

In Study 2, participants (n=101) underwent the social context manipulation from Study 1 during concurrent recording of EEG in order to test the default network interference hypothesis of SET. EEG power in the theta band (4-8 Hz) at frontal midline sites was used as a marker of default network suppression. We found evidence for default network interference, as frontal theta, which led to better accuracy, was reduced during SET. In addition, individuals high in FNE showed less improvement in accuracy as a result of higher frontal theta, suggesting less efficient neural processing. Threat again predicted overall better accuracy despite predicting decreased frontal theta, indicating competitive mediation. Participants reported exerting more effort during SET, which led to improved accuracy, suggesting that individuals may have compensated for lower frontal theta during SET by increasing cognitive effort. Together, these studies elucidate a potential neural mechanism for the cognitive effects of social-evaluative threat, suggest methodological decisions to consider in social anxiety research, and help explain cognitive impairments seen as a result of SET and social anxiety.

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The Hidden Costs of Social-Evaluative Threat: A Default Network Interference Hypothesis

The feeling of being evaluated can produce far-reaching negative consequences on performance. For example, social-evaluative threat (SET) can lead athletes to "choke" under pressure, can impair one's social abilities, and can heighten errors during cognitive tasks (Baumeister & Showers, 1986; Eysenck & Derakshan, 2011; Kashdan & Roberts, 2004; Mesagno, Harvey, & Janelle, 2012; Schmader, Johns, & Forbes, 2008). Individuals high in social anxiety, a trait characterized by excessive self-focus and fear of being evaluated by others, may be especially sensitive to the deleterious effects of SET. Intriguingly, people high in social anxiety show performance decrements even in experimental situations in which threat of social evaluation is not made explicit; this suggests the possibility that mere experimenter presence may induce feelings of evaluation that lead to cognitive deficits (Cody et al., 2014; Maresh et al., 2014). Researchers have explored the role of overt evaluation on social performance among socially anxious people, but little is known about the degree to which, or whether, more subtle social contexts interact with social anxiety to affect performance on *non-social* tasks. Non-social task performance may be an underappreciated topic in social anxiety research, especially given the broad effects on cognitive function generally considered to be part of social anxiety as a clinical syndrome. Further, although the psychological mechanisms linking SET to task performance are increasingly well characterized, the neural mechanisms mediating those links are poorly understood. Understanding *why* and *how* SET affects cognitive performance at the neural level may provide additional targets for clinical intervention.

The goals of this dissertation are twofold: 1) to examine how individual differences in trait social anxiety interact with situational social-contextual factors to influence cognitive performance interference, and 2) to investigate activity in the default network as a possible neural mediator for this interference. Specifically, Study 1 investigated how manipulating the degree of SET in the environment influenced performance deficits and how trait fear of negative evaluation (FNE), a construct related to cognitive biases seen in social anxiety (Clark & Wells, 1995), moderated the effects of SET context on performance of a working memory task. Study 2 implemented electroencephalography (EEG) to test the *default network interference hypothesis of SET*—that difficulty suppressing activity in the default network, a network of brain regions broadly related to self-referential thought, mediates the interactive effect of social-evaluative context and trait social anxiety on performance interference, particularly on tasks utilizing working memory. This theory posits that situations high in SET may generally increase internal attention that can interfere with working memory performance, but for individuals high in social anxiety, even social contexts with presumably low SET (e.g., mere presence of an unfamiliar person) could divert attention toward internally-focused cognitions, represented by heightened activity in the default network. This default network interference reduces attention to the task at hand by promoting a conflict between internal and external attentional foci. One characteristic of social anxiety may be that this internal-external conflict is induced even in minimally social situations, a vulnerability that may be pronounced when task demands are high. A general model for the default network interference hypothesis of SET is depicted in Figure 1.

Internal attention in social anxiety

Social anxiety entails attentional biases both outward, toward scanning the environment for potential social threat cues, and inward, toward internal physiological indications of anxiety, negative self-appraisals, and anxiogenic mental imagery (Hofmann, 2007; Rapee & Heimberg, 1997). While both external and internal attention biases are important to the etiology of social anxiety disorder, established models of social anxiety highlight the role of internal attention in maintaining the disorder (Clark & Wells, 1995; Rapee & Heimberg, 1997). Indeed, it is suggested that while socially anxious individuals may initially show heightened orienting to external social threat cues, their attention then turns toward and remains focused on internal processes (Mellings & Alden, 2000; Perowne & Mansell, 2002; Rapee & Heimberg, 1997). While "internal attention" can refer to attention to internal body cues, a recent update to the model proposed by Rapee and Heimberg emphasizes the role of negative thoughts and imagery in particular (Heimberg, Brozovich, & Rapee, 2010). It is worth noting this distinction, as attention to one's bodily cues and attention to one's self-generated thoughts and images appear to be mediated by distinct neural substrates (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004). For the purposes of this dissertation, the term "internal attention" will be used to refer to self-generated thoughts and images likely to be subserved by default network activity.

Despite the importance of internal attention in theoretical models of social anxiety, research has largely focused on external threat biases. This may be due to the multitude of well-validated paradigms for measuring external attention biases, such as the dot probe and emotional Stroop tasks, and the relative difficulty in measuring attention toward covert internal thoughts. Studies have explored biased attention toward internal sensations such as one's heartbeat (Mansell, Clark, & Ehlers, 2003), but, as described above, attention to physiological cues is essentially still attention guided by perceptual input and thus is likely served by different cognitive and neural processes than attention to internally-generated thoughts, such as imagery or self-appraisals. And while disruption in performance on certain tasks may seem to imply diversion toward internal thoughts, it should be noted that a reduction in external attention does not necessitate that an increase in internal attention occurred—rather, attention toward other external cues or attentional failure altogether may be more parsimonious interpretations. Thus, it is important to actually test whether changes in internal attention can account for observed decrements in performance given there is currently little empirical evidence of the role of internal attention in impairing task performance in social anxiety. Fortunately, the use of neuroimaging can be used to infer such mental processes.

Internal attention and the default network

The default network, which includes the medial prefrontal cortex (mPFC), precuneus/posterior cingulate cortex (PCC), and lateral temporal and parietal areas, was originally identified as *deactivated* during task-focused activities and, inversely, more activated during periods of rest or less task-demanding conditions. Studies have subsequently linked the default network to a spectrum of cognitive processes including episodic memory, mind wandering, perspective taking, and introspection (Andrews-Hanna, 2012; Buckner, Andrews-Hanna, & Schacter, 2008; Moran, Heatherton, & Kelley, 2009). Default network processes, while wide-ranging in function, share the qualities of being generally self-referential in content and independent from perceptual input, as is reflected in the many terms that have been used to describe default network processes, such as "self-generated thoughts,” "stimulus-independent thought," and "internal mentation" (Andrews-Hanna, 2012; Andrews-Hanna, Smallwood, & Spreng, 2014; Mason et al., 2007). As such, the default network appears to be a strong correlate of what is referred to in this dissertation as "internal attention."

Default network activation interferes with cognitive performance. Default network deactivation during tasks is thought to indicate the diversion of attention away from self-generated thoughts to allow focus on external task performance (Sheline et al., 2009).

Accordingly, difficulty suppressing default network activity during externally-directed tasks is associated with self-reported distraction and performance deficits (Christoff et al., 2009; Hinds et al., 2013; Kühn et al., 2011). This may be particularly evident across working memory tasks (Anticevic, Repovs, Shulman, & Barch, 2010; Sambataro et al., 2010). Indeed, the default network shares a stable negative correlation with regions related to cognitive performance, including those involved in working memory processes, such as the dorsolateral prefrontal cortex (dlPFC) and the anterior cingulate cortex (ACC), both at rest and during task completion (Fox et al., 2005; Uddin, Kelly, Biswal, Castellanos, & Milham, 2009). Stronger negative correlations between these so-called “task-positive” areas and the “task-negative” default network have been shown to predict improved performance on working memory tasks (Sala-Llonch et al., 2012), suggesting that sufficient suppression of default network activity by task-positive areas is correlated with better performance. Along these lines, Sonuga-Barke and Castellanos (2007) have proposed the *default-mode interference hypothesis*, suggesting that spontaneous intrusions of default network activity can lead to task-related interference; we extend this hypothesis to suggest that this interference can occur as a result of perceived social-evaluative threat.

Social-evaluative threat and the default network

Given the difficulty socially anxious individuals have disengaging from self-focused thoughts, it is not surprising that alterations in default network activity have been observed in social anxiety. Individuals high in social anxiety show difficulty suppressing default network activity during social-evaluative tasks when, for example, receiving positive or negative feedback (Blair et al., 2008; Heitmann et al., 2014). Of interest, we previously identified heightened default network activity in socially anxious individuals performing a monetary reward task without being under any overt (e.g., made explicit by the experimenter) social threat, suggesting the possibility that the socially anxious individuals perceived evaluation in the experimental context (Maresh et al., 2014). Furthermore, activity in the precuneus partially statistically mediated the relationship between social anxiety and reaction times on this task (Maresh, 2015). Alterations in default network activity have been observed during social-evaluative tasks even when not accounting for social anxiety, suggesting that sufficiently intense SET may induce disruptions even in the absence of high trait social anxiety. For example, when anticipating giving a speech in front of an evaluative audience, healthy individuals exhibited higher activity in the ventral mPFC (van Ast et al., 2014).

Social-evaluative context, trait social anxiety, and working memory

In support of the default network interference hypothesis, several lines of research have converged on the idea that working memory processes are impaired by SET, both in its state or contextual form, as seen in stereotype threat and psychosocial stress paradigms, and in its trait form, as seen in social anxiety.

Stereotype threat and working memory. Stereotype threat occurs when an individual experiences fear related to being negatively evaluated for belonging to particular social group. A well-supported body of work has found that priming stereotype threat interferes with performance on tasks involving working memory capacity, an effect seen across individuals from a variety of different social groups (Beilock, Rydell, & McConnell, 2007; Schmader & Johns, 2003). Theories of stereotype threat suggest these effects are due in part to the diversion of attention to task-irrelevant information, such as monitoring one's self and one's performance (Schmader et al., 2008). Accordingly, mind-wandering has been identified as a mediator of poor math test performance in individuals under stereotype threat (Mrazek et al., 2011), a process likely to be related to default network activity. Of note, disruptions in working memory due to stereotype threat might only be evident when task demands exceed available working memory resources. In support of this, Beilock, Rydell, and McConnell (2007) found that inducing gender-related stereotypes reduced women's performance on a set of math problems, but only when the math problems were complex. Thus, task difficulty might be an important moderator of default network interference.

Psychosocial stress and working memory. Studies of psychosocial stress often employ paradigms that involve the performance of stressful tasks in front of an evaluative audience, such as the Trier Social Stress Task (TSST; Kirschbaum, Pirke, & Hellhammer, 1993), to induce feelings of SET. Following administration of the TSST, slower reaction times have been found on the Sternberg working memory task, but only in high load conditions (Oei, Everaerd, Elzinga, Van Well, & Bermond, 2006). Similarly, impairments were found following the TSST in both reaction times and accuracy on the n-back working memory task, but only during the first block of trials (Schoofs, Preuß, & Wolf, 2008). Thus, while reductions in working memory performance have been observed following administration of the TSST, these effects appear susceptible to influence by task difficulty or habituation. Importantly, these paradigms often examine cognitive performance *following* the experience of SET, as opposed to *during*; thus, disruptions in task performance in these paradigms may be mediated by different processes, such as fatigue or reduced motivation.

Similar deficits in performance have been seen during ongoing SET. For example, reductions in digit span performance were observed when participants were given instructions intended to induce evaluation anxiety; these reductions were mediated by negative off-task self-dialogue (Coy, O'Brien, Tabaczynski, Northern, & Carels, 2011). Interestingly, in a study comparing digit span performance in individuals who showed elevated cortisol in response to a social stressor compared to those who did not, cortisol responders were found to exhibit working memory deficits compared to non-responders only when performing the task in front of an audience, but not prior to this social stressor or when recovering from it (Elzinga & Roelofs, 2005). Thus, concurrent SET may be a more potent disruptor of cognitive performance than recovery from SET.

Social anxiety and working memory. Socially anxious individuals, who experience chronic fears of being evaluated by others, also exhibit deficits in working memory, particularly when feeling socially threatened. For example, individuals high in social anxiety exhibited poorer performance on a digit span task after giving an impromptu speech (Wenzel & Holt, 2003). On the other hand, socially anxious individuals showed poorer working memory capacity for neutral words but did not differ in working memory capacity for social threat words compared to non-socially anxious individuals (Amir & Bomyea, 2011). In this vein, attentional control theory (Eysenck & Derakshan, 2011) proposes that anxiety (of any type) impairs cognitive performance in part through decreasing efficiency of the central executive of working memory, which directs an individual's attention to relevant information while simultaneously suppressing irrelevant information (Baddeley, 1992). Consequently, attentional control theory suggests that anxiety impairs inhibition of task-irrelevant stimuli and shifting functions, leading anxious individuals to more easily become distracted by unwanted, task-irrelevant cognitions (Wieser, Pauli, & Mühlberger, 2009). When the content of the task involves social threat words, however, socially anxious individuals may perform better due to the increased salience of those cues (Amir & Bomyea, 2011).

Interestingly, findings suggest that trait social anxiety might actually confer some working memory enhancements, at least under certain circumstances (Moriya & Sugiura, 2012;

Wenzel & Holt, 2003). Moriya and Sugiura (2012) found that social anxiety corresponded with greater working memory performance on a task involving emotionally-neutral stimuli; however, when visual distractors were introduced, the positive association between social anxiety and working memory was no longer evident. The authors suggested that while social anxiety may correlate with stronger working memory capacities, the need for socially anxious individuals to allocate their attention more widely to be vigilant for threats masks this high visual working memory capacity, in line with attentional control theory.

One limitation seen across social anxiety studies is that they often do not adequately address the potential influence of experimental social context on performance. Given that the mere perception of an audience may be sufficient to activate fears in social anxiety (Clark & Wells, 1995; Rapee & Heimberg, 1997) and that socially anxious individuals may be especially sensitive to task-irrelevant distractors (Eysenck & Derakshan, 2011; Moriya & Sugiura 2012), the presence of an experimenter is likely to have effects on socially anxious individuals that could negatively impact performance even on non-social tasks. In support of this, performance deficits have been seen in socially anxious individuals during tasks lacking social content, implying that interference could not be attributed to a social aspect of the task stimuli (Cody et al., 2014; Maresh et al., 2014). Thus, social anxiety may have interacted with unaccounted-for aspects of the environment, making it unclear whether cognitive differences seen in social anxiety are related to trait-like differences in abilities or to state differences that have been activated by social-contextual factors. The proposed studies will attempt to disentangle this confound by introducing conditions designed to differentiate between actual working memory deficits in social anxiety and effects of experimenter presence.

Internal attention as a mechanism for SET-related performance interference

Taking together accounts from the aforementioned literature, a general psychological mechanism by which SET interferes with cognitive performance is proposed: that the perception of being evaluated directs one's attention to more self-focused thoughts, a process labeled here as "internal attention," and this diversion of attention leads to performance deficits across a variety of cognitive tasks, provided the intensity of the internal attention and/or the difficulty of the task is great enough to cause interference. Although default network activity may affect cognitive performance broadly, its detrimental effects may be seen more readily in cognitively-demanding tasks requiring use of the task-positive network, such as working memory tasks, whose activity is often negatively correlated with that of the default network (Sala-Llonch et al., 2012), Additionally, anxiety may consume attentional resources that reduce efficiency of the working memory system (Eysenck & Derakshan, 2011). For these reasons, working memory has been selected as an initial cognitive process to test that may be interrupted by default network activity. Because task difficulty has previously been shown to moderate effects of social threat on performance and is likely to influence default network interference, the n-back has been selected as the working memory task for this dissertation. The n-back is a working memory task in which load can be manipulated to compare effects of varying difficulty level. Of note, working memory, defined as one's ability to temporarily store and manipulate information, is critical to higher-level cognitive skills generally; thus, impairment of working memory processes may have widespread cognitive effects.

Frontal theta in electroencephalography and the default network

Because of constraints inherent to the fMRI environment (e.g., requiring participants to remain still and prone while isolated in the bore of a scanner), utilizing EEG may offer more flexibility in regards to manipulating social-contextual factors. EEG is a non-invasive, costeffective technique for recording brain activity. By capturing electrical activity at the scalp, EEG records coordinated changes in the activity of large groups of neurons. This activity can then be decomposed into component frequencies to determine the amplitude, or power, of frequency bands present in the EEG signal across time. Although specific localization of these frequencies to regions of the brain is difficult, comparing EEG findings with results from neuroimaging or, better yet, combining fMRI with simultaneous EEG recording can be used to predict the origins of EEG signals. Several studies have used combined these methods to identify EEG correlates of default network activity.

Converging evidence suggests theta power (4-8 Hz) recorded at frontal midline electrodes corresponds with suppression of default network activity. Frontal theta activity has been observed across a broad range of cognitively-demanding tasks, including tasks that require attention and short-term memory (e.g., Burgess & Gruzelier, 1997; Lazarev, 1998), and has been shown to increase with working memory load (Gevins, Smith, McEvoy, & Yu, 1997; Krause et al., 2000; Onton, Delorme, & Makeig, 2005). To localize the neural source of frontal theta activity, Scheeringa et al. (2008) simultaneously recorded EEG and fMRI during resting state and found that oscillations in frontal theta activity corresponded with reduced activity across several regions of the default network, primarily the mPFC, but also the inferior frontal gyrus, medial temporal gyrus, inferior parietal lobule/angular gyrus, precuneus, and cerebellum; no positive associations between theta power and neural BOLD activations were found. Additional studies combining fMRI and EEG have found frontal theta to correspond with decreased default network activity across cognitive tasks, including mental arithmetic and working memory tasks (Meltzer, Negishi, Mayes, & Constable, 2007; Mizuhara, Wang, Kobayashi, & Yamaguchi, 2004; Scheeringa et al., 2009). Therefore, frontal theta power appears to be a stable index of default network suppression.

Studies have observed negative correlations between frontal theta power and levels of stress and anxiety (Knyazev, Slobodskaya, & Wilson, 2002; Mizuki et al., 1992; Suetsugi et al., 2000). A recent study observed that the extent to which frontal theta power increased during mental arithmetic was attenuated when participants were primed with a stressful video clip, and this reduction in theta corresponded with slower reaction times on the arithmetic task (Gärtner, Grimm, & Bajbouj, 2015), a pattern supportive of the default network interference hypothesis. This suggests a role for stress-related alterations in frontal theta activity as a contributor to task interference. Study 2 used EEG to specifically target frontal theta activity to examine its mediating role in SET-related performance interference.

Overview and hypotheses

The default network interference hypothesis of SET was tested in two studies. Study 1 aimed to validate a novel social context manipulation that tested the effects of SET and social anxiety on working memory performance. Results from this study were used to refine the approach for Study 2. Unlike social threat manipulations that simply compare overt social threat to non-threat, this manipulation examined a finer degree of contextual differentiation. Namely, given that socially anxious people may interpret an audience that would seem innocuous to most people as threatening, working memory performance (measured at two difficulty levels of the n-back task) was examined under three within-subjects conditions: one in which the participant was completely alone ("Anonymous"), one in which an experimenter was present but non-evaluative ("Presence"), and one in which the experimenter was present and explicitly evaluative ("Threat"). A stratified sampling approach was used to recruit undergraduates with a wide range of social anxiety from a psychology department participant pool, and trait social anxiety was measured using the straightforward-worded items from the Brief Fear of Negative Evaluation Scale (BFNE-S). It was hypothesized that levels of FNE would correspond with poorer performance (i.e., longer reaction times and lower accuracy) in the Presence condition, which will be potentiated in the Threat condition, but would show no association with performance in the Anonymous condition. Further, effects of the Presence and Threat conditions were expected to be stronger during more difficult task trials (i.e., 3-back vs. 2-back trials).

Study 2 tested the default network interference hypothesis of SET using EEG. As before, participants were recruited from a psychology department participant pool and sampled to have a wide range of social anxiety. They performed the n-back task at two difficulty levels under the social context manipulation described above, with modifications determined from the results of Study 1. Additionally, EEG caps were affixed to participants prior to task performance to record frontal theta activity, a proxy for default network suppression. This study tested a moderated mediation model, in which the effect of social context on n-back performance was predicted to be mediated by change in frontal theta power, and the degree of this mediation was predicted to depend on trait social anxiety. This is thought to represent difficulty diverting attention from internal, self-focused thoughts. Further, n-back difficulty level was predicted to moderate the effect of frontal theta power on task performance. In sum, these studies sought to establish and validate a novel social context manipulation, examine the interactive effect of contextual SET and trait social anxiety on working memory performance, and test default network activity as a neural mediator of this effect.

Study 1: Does trait social anxiety interact with social context to predict working memory performance?

Methods

Participants and recruitment

Participants (n=61; 77.1% women) for Study 1 were recruited through the University's psychology participant pool based on their responses to the 20-item Social Phobia Scale (SPS; Mattick & Clarke, 1998), administered as part of the department-wide pre-selection survey. The mean age of the sample was 18.52 years (*SD*=1.04, range=17-24). The reported races of the participants were White (n=32; 52.5%), Asian (n=17; 27.9%), Black/African American (n=6; 9.8%), and mixed race (n=6; 9.8%). Participants were recruited using a stratified sampling method to ensure roughly equal numbers of participants with low, moderate, and high levels of social anxiety, with low levels defined as scores less than 1 *SD* below the mean of the total scores in the participant pool, moderate levels as those between -1 and +1 *SD*, and high levels as scores greater than 1 *SD* above the mean. Specifically, SPS scores were examined halfway through recruitment and again at the end of each subsequent week, and eligibility was restricted to individuals with low, moderate, or high SPS scores in the participant pool as needed.

Social context manipulation

The social context paradigm being tested in this study consisted of performing the n-back, a working memory task, under three conditions, "Anonymous," "Presence," and "Threat," that vary in their degree of social and evaluative characteristics. Each participant underwent all three conditions with order counterbalanced across participants, and measures of state affect were collected after each condition. After performing a brief practice version of the n-back, participants were informed that they would be performing "several rounds" of the n-back task but were not given descriptions of the condition manipulations until debriefing.

Anonymous condition. In the Anonymous condition, participants were told the following instructions: they are to complete the task alone in the room, their scores will be recorded for later data analysis but will be confidential, and the experimenter will have no knowledge of their performance. Specific to this condition, the experimenter then stated that he or she needed to go prepare some paperwork; the experimenter then left the room. This manipulation was intended to reduce, to the degree possible in a psychology experiment, feelings of social presence and of being evaluated.

Presence condition. In the Presence condition, the experimenter provided the same instructions as in the Anonymous condition but did not state that he or she would be leaving the room to complete paperwork. Instead, the experimenter then sat adjacent to the participant at an angle at which the participant's monitor was not visible. The experimenter then became engaged in reading an unremarkable document (e.g., a black-and-white printed article) to appear occupied. This was intended to reduce feelings that the participant's performance was being evaluated while still maintaining social presence.

Threat condition. In the Threat condition, the experimenter informed the participant that he or she would be watching their performance and recording each time a mistake was made for the purpose of comparing the participant's performance to that of his or her peers. The experimenter then sat adjacent to the participant as he or she performed the task, similar to the Presence condition but with the monitor turned slightly to be visible to the experimenter, and recorded the number of mistakes the participant made on a sheet of paper. This condition was designed to contain both social presence and an evaluative component.

Materials

Assessment of working memory: Visual n-back task. In visual n-back tasks, participants view a sequence of letters or numbers on a computer screen with the goal of identifying when the stimulus presented matches the one seen *n* steps earlier (Gevins & Cutillo, 1993). This task measures working memory capacity and can be modified for different levels of difficulty by changing the number of steps back one must remember. Successfully performing this task involves inhibiting distracting thoughts and updating working memory, two components hypothesized to be affected by the need to switch from self-focused to task-relevant thoughts.

In this study, the n-back task was administered using a modified version of the task available from PsyToolkit (psytoolkit.org; Stoet, Windows, & Macintosh, 2010). Participants were presented with sequences of letters of the alphabet, each randomly displayed from one of fifteen letters, chosen on the basis of their visual distinctiveness. Participants were instructed to press the letter "M" for target letters and the letter "N" for all other letters (thus, each trial required a response in order to be correct); 33% of the stimuli were target letters and 67% were non-target letters. Each letter was presented for 2000 ms followed by an interstimulus interval of 500 ms during which the participant could still make a response. After responding (or failing to respond), two bars above and below the letter flashed either green or red to reflect that the participant's answer was correct or incorrect, respectively.

To examine the potential moderating effect of task difficulty, participants completed eight alternating blocks of 2-back and 3-back trials within each condition (cf. Schoofs et al., 2008). Each block contained 20 trials (if 2-back) or 21 trials (if 3-back). Because the first two trials for 2-back and three trials for 3-back cannot be target trials, they were removed from analysis, leaving 18 analyzable trials within each block. This yielded a total of 72 trials of 2-back and 72 trials of 3-back within each condition, for a total of 144 trials over approximately 6 minutes for each condition. Performance on the n-back task was measured both by reaction times (RTs) and accuracy for each trial.

State responses to social context manipulation. Following each of the three social context conditions, participants completed four items on the computer using a 0 to 100 slider to assess the greatest degree to which they experienced certain states during the task they just completed. These questions were, "How anxious did you feel?", "To what extent did you feel like you were alone during this task?" (with higher scores indicating feeling less alone), "To what extent did you feel like you were being monitored?", and "To what extent did you feel like you were being negatively evaluated?" During the Anonymous and Presence conditions, the experimenter either was not present or could not see the screen as the participant responded. During the Threat condition, the experimenter turned away from the participant's screen to reduce possible influence of experimenter observation on participant responses. These measures served as manipulation checks for the social context conditions. Specifically, we anticipated that these measures would be elevated when another person was in the room and would be highest during overt social evaluation.

Trait measures[1]. The Social Phobia Scale (SPS; Mattick & Clarke, 1998) was administered as part of the university participant pool pre-test to use as the initial social anxiety screener when recruiting for this study, as described in the Participants and Recruitment section. The SPS is a 20-item questionnaire that assesses fears of being scrutinized or observed (e.g., *"I get nervous that people are staring at me as I walk down the street," "I worry I might do something to attract the attention of others").* Participants are asked to indicate the degree to which each statement is characteristic of them using a 5-point Likert scale ranging from 0="Not

[1] Several additional measures were collected as part of a larger study. Given the specific hypotheses for this study, only the BFNE-S was used as a trait moderator for analyses. A full list of measures is available from the author.

at all" to 4="Extremely." This scale showed excellent reliability in this sample (Cronbach's alpha=.94).

The Brief Fear of Negative Evaluation Scale-Straightforward items (BFNE-S; Leary, 1983; Rodebaugh et al., 2011) was administered at the time of the lab study session for use as a measure of trait social anxiety. The original BFNE is a 12-item scale that measures the degree to which a person experiences apprehension at the prospect of being evaluated negatively (e.g., *"I am afraid that others will find fault with me," "I am usually worried about what kind of impression I make"*) using a 5-point Likert scale ranging from 0="Not at all characteristic of me" to 4="Extremely characteristic of me." The BFNE-S was chosen as the trait measure because of its emphasis on fear of negative evaluation (FNE) as a specific cognitive mechanism related to social anxiety rather than on more general social anxiety symptomatology. Because the reverse-scored items on the original BFNE may exhibit poor reliability and validity (e.g., Rodebaugh et al., 2011), only the eight straightforward-worded items were used (BFNE-S). These eight items showed excellent reliability (Cronbach's alpha=.92).

The depression subscale from the short-form version of the Depression Anxiety Stress Scales (DASS-D; Lovibond & Lovibond, 1995) and the trait version of the State-Trait Inventory of Cognitive and Somatic Anxiety (STICSA; Ree, French, MacLeod, & Locke, 2008) were administered during the lab study. Because social anxiety is characterized by both decreased positive affect, as seen in depression, and increased negative affect, as seen in general anxiety (Brown, Chorpita, & Barlow, 1998), these scales were used to examine the unique contribution of social anxiety to working memory performance after controlling for depression and general anxiety symptoms. These scales showed good reliability in this sample (DASS-D: Cronbach's alpha=.87; STICSA: Cronbach's alpha=.90).

Procedure

Upon arrival to the laboratory, participants were informed that they would be completing several rounds of a memory task while physiological measures were recorded and would then complete some questionnaires assessing personality characteristics. Information regarding the different social-contextual conditions was not provided until the end of the experiment.

Following informed consent, participants were attached to psychophysiological equipment, and a two-minute baseline recording of heart rate and skin conductance was conducted (psychophysiological data are not discussed as part of this study). After completing a brief 20-trial practice version of the 2-back and 3-back task to ensure comprehension, participants performed the n-back task again under the three social context conditions (Anonymous, Presence, and Threat), with condition order counterbalanced across participants, while psychophysiological data were continuously recorded during each condition. State measures were collected immediately following each condition. After completion of the social context manipulation, participants completed a battery of questionnaires assessing levels of several facets of social anxiety, as well as general anxiety and depressive symptoms. Questionnaires were administered last in the study to prevent priming of social anxiety constructs prior to the social context manipulation. Finally, participants were debriefed and received course credit for their participation.

Plan for analyses

Data scoring and reduction. The SPS, BFNE-S, DASS-D, and STICSA were each scored by summing across all items, following scoring procedures described in the original publications. Questionnaire scores were mean-centered prior to subsequent analyses. For n-back data analysis, trials were excluded if participant RT was less than 200 ms (<1% of trials) or if the participant did not give a response (<.1% of trials). All resulting trials were used for analyses of accuracy data. For analyses of RTs, only trials in which participants made a correct response were used.

Manipulation check: State measures. To confirm that the social context manipulation had the intended effects, a series of linear mixed models were conducted with each state measure predicted by a fixed effect of condition (three-level factor: Anonymous, Presence, and Threat), with a random intercept for each participant. Pairwise t-tests with Satterthwaite approximations to degrees of freedom were then performed to determine significant differences between conditions.

<u>*Primary analyses*</u>

To account for the clustered nature of the data in this study, a mixed-effects regression modeling approach was used. This analytic method has several well-documented advantages over more traditional repeated-measures ANOVA approaches, including improved flexibility in modeling continuous-categorical variable interactions, more robust, unbiased handling of missing data, and the ability to model variations in responses across time (see Baayen, Davidson, & Bates, 2008; Nich & Carroll, 1997). One common difficulty in mixed modeling, however, is determining the "optimal" random effects structure for the study design. Barr et al. (Barr, Levy, Scheepers, & Tily, 2013) proposed that researchers should use the maximal random effects structure justified by the study design (i.e., that random intercepts and slopes should be specified where they are expected to exist in the data) when performing confirmatory analyses due to inflated Type I error rates present in under-specified models. On the other hand, fitting a maximal model in some cases may prove overly-conservative while leading to a loss of power (Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2015). Because Study 1 sought to test a novel experimental paradigm, two random effects structures (described in detail below) were compared: the maximal model justified by the data, to minimize Type I error, and a random intercept-only model, to maximize power. Each model was fitted using the “lme4” package in R (Bates, Mächler, Bolker, & Walker, 2015; R Core Team, 2013).

Interactive effects of social context and fear of negative evaluation on working memory performance. To examine the role of trait FNE and social context condition on working memory performance, linear mixed models were conducted for each performance outcome variable (RT and accuracy). For all models, fixed effects included n-back difficulty (two-level factor: 2-back and 3-back), condition (three-level factor: Anonymous, Presence, and Threat), scores on the BFNE-S (continuous; mean-centered), all two-way interaction terms, and the three-way interaction term. When predicting reaction times, random effects for the maximal model included random by-participant slopes for condition, n-back level, and their interaction and a random intercept for participant; random intercepts for block and trial nested within block were additionally included to account for general variability in blocks and trials within blocks across participants. The model was specified in R as:

```
Reaction times ~ condition*nback*FNE + (condition*nback|ptp) +
(1|block/trial)
```

In mixed models, failures of convergence can occur when there is too little data given the number of parameters in the model. Accordingly, when predicting accuracy, the random effects structure had to be reduced due to the reduction in data when looking at a binomial outcome variable, such that only a by-participant random slope for condition could be fitted. Further, because accuracy data followed a binomial distribution, a generalized linear mixed model with a binomial link was used. This model was specified in R as:

```
Accuracy ~ condition*nback*FNE + (condition|ptp)
```

Random effects for the intercept-only models for both reaction times and accuracy included random intercepts for participant, block, and trial within block, specified as:

```
WM performance (RT or Accuracy) ~ condition*nback*FNE + (1|ptp) +
(1|block/trial)
```

Planned comparisons using Satterthwaite approximations to degrees of freedom were then conducted to probe pairwise effects.

Supplementary analyses. To examine other potential important moderators of performance, we ran several additional analyses assessing the effects of gender, depression, trait anxiety, and condition order. Because there were only 14 men in our sample, there was insufficient power to use gender as a factor. Instead, we ran the same models predicting RTs and accuracy described above on just the sample of women (N=47). To assess whether effects of FNE on performance were unique to FNE, depression and trait anxiety scores were each included as a covariate in separate models predicting RTs and accuracy. To assess effects of condition order on performance, separate mixed models were conducted for RTs and accuracy with condition, condition order, and their interaction as fixed effects. Random effects included a random by-participant slope for condition order. Condition itself could not be included as a random slope with condition order due to lack of convergence.

Sample size considerations. Due to the inherently complicated nature of conducting power analyses for mixed effects models (requiring integrating higher- and lower-level units, within- and between-unit covariances, and other factors, which may be further complicated when the parameter of interest is a cross-level interaction; see Mathieu, Aguinis, Culpepper, & Chen, 2012), straightforward guidelines for conducting mixed model power analyses are not available. Researchers have conducted simulation studies to approximate sample sizes needed to detect medium-sized effects in mixed effects designs. Mathieu et al. (2012) determined that combining a Level 1 sample size of at least 18 and a higher level sample size of at least 35 provides over 80% power to detect a medium-sized cross-level interaction effect. While this recommendation is restricted to 2-level designs, the presence of additional levels, as in the proposed design, would only increase power. In the absence of clear recommendations, this study recruited a sample of 61 participants, and Level 1 (trial number) sample sizes were kept at a minimum of 18 per cell for all combinations of higher-level factors. Results from this study were used to inform sample size considerations for Study 2.

Study 1 Results

Manipulation check: State measures

To evaluate whether the social context manipulation had the intended effect on participants, differences among state measures (feeling anxious, not alone, monitored, and negatively evaluated) were assessed. As hypothesized, participants reported monotonic increases in all state measures from the Alone to Presence to Threat conditions (Figure 2, all ps<0.05), except for negative evaluation. In other words, participants felt more anxious, less alone, and more monitored when another person was in the room than when they were alone; this effect was further heightened if the other person was overtly evaluating them. Levels of negative evaluation were greater only in the Threat condition compared to the Presence and Anonymous conditions (ps<0.05). Of note, negative evaluation scores were negatively skewed across all conditions, with 41%, 38%, and 28% of participants reporting "0" negative evaluation in the Anonymous, Presence, and Threat conditions, respectively.

Interactive effects of social context, n-back difficulty, and trait fear of negative evaluation on working memory performance.

To evaluate the effect of SET on working memory performance, the interactive effects of social context, FNE, and n-back difficulty level on both RT and accuracy were assessed using mixed effects models. Table 1 compares the ANOVA results for the maximal and random intercept-only models predicting RTs; Table 2 shows the analysis of deviance table for the random slope model predicting accuracy.

Reaction times

Maximal model. A significant main effect of n-back level on RTs emerged ($F(1, 23)=14.90$, $p<0.001$), such that participants were slower to respond to 3-back trials compared to 2-back trials (2-back M=730.30, SD=268.55 ms; 3-back M=793.17, SD=298.50 ms). There was no significant main effect of condition on RT. A two-way interaction between condition and n-back level trended toward significance ($F(2, 58)=2.80$, $p=0.069$). This was subsumed by a significant three-way interaction between condition, n-back level, and FNE, indicating that the interactive effects of condition and n-back level on RT were moderated by FNE ($F(2, 58)=5.15$, $p=.009$; Figure 3). To further decompose this interaction, all possible two-way interactions were tested at different levels of the third variable. First, two-way interactions between condition and FNE were tested at each n-back level; no significant interactions emerged. Second, two-way interactions between condition and n-back level were tested at high (+1 SD) and low (-1 SD) levels of FNE using the simple slopes method recommended by Aiken and West (1991). For participants with high levels of FNE, the difference between 2-back and 3-back trials was greater in the Threat compared to Anonymous condition ($t(58)=3.30$, $p=.002$) and in the Threat compared to Presence condition. Finally, two-way interactions between n-back level and FNE were tested within each condition. No significant interactions emerged in any condition.

Random intercept-only model. When accounting for random intercepts only, significant main effects of condition and n-back level and significant interactions between condition and n-back level, condition and FNE, and n-back level and FNE emerged (Table 1). These were subsumed by a three-way interaction between condition, n-back level, and FNE. As hypothesized, during 3-back trials, FNE corresponded with slower RTs during the Presence condition compared to the Anonymous condition ($t(23223)=2.21$, $p=.027$) and during the Threat condition compared to the Presence condition ($t(23040)=2.04$, $p=.042$) and Anonymous condition ($t(23228)=4.25$, $p<.0001$). During 2-back trials, FNE corresponded with slower RTs during the Presence condition compared to the Anonymous condition ($t(22930)=3.98$, $p<.0001$) and Threat condition ($t(22924)=4.35$, $p<.0001$). The effect of FNE during 2-back trials did not differ between the Anonymous and Threat conditions.

<u>*Accuracy*</u>

Random slope model. When predicting accuracy, a significant main effect of n-back level emerged that was subsumed by a significant two-way interaction between condition and n-back level ($X^2(2)=20.04$, $p<0.0001$; Table 2). As seen in Figure 4, comparisons of slopes indicated that during 2-back trials, accuracy was greater in the Threat condition compared to the Presence condition ($z=2.96$, $p=.003$) and Anonymous condition ($z=4.46$, $p<.0001$). Accuracy did not differ during 2-back trials in the Presence compared to Anonymous condition ($z=1.67$, $p=.095$). During 3-back trials, accuracy did not differ based on condition. FNE did not moderate any effects of condition or n-back level on accuracy, nor was the three-way interaction between FNE, condition, and n-back significant ($X^2(2)=1.57$, $p=.455$).

Random intercept-only model. The random intercept-only model for accuracy did not differ substantially from the maximal model and thus is not discussed further.

Supplementary analyses: Gender, depression and trait anxiety, and order effects.

Gender, depression, trait anxiety, and condition order were additionally examined as moderators of performance to assess possible alternative explanations for our findings.

Gender. We examined whether our findings changed when looking at the subset of women only (n=47). The pattern of significance did not differ for RTs; for accuracy, condition became a significant predictor, but there were still no interactions with FNE.

Depression and trait anxiety. When including depression or trait anxiety as a covariate, the pattern of significance did not change for RTs. For accuracy, including either depression or trait anxiety scores resulted in a significant condition effect that continued to be subsumed by a two-way interaction between condition and n-back.

Order effects. Because of the within-subjects design of this study, practice and/or fatigue may have affected performance on later conditions. We examined whether condition order interacted with condition and FNE to influence RTs or accuracy. Condition order showed a main effect on RTs and accuracy such that RTs were faster and accuracy was higher on each subsequent condition (ps<0.05), suggesting improvement rather than fatigue. Levels of FNE and condition did not interact with order effects (ps>0.05).

Study 1 Conclusions

Study 1 tested a novel social context manipulation intended to parse whether experimenter presence affects levels of anxiety and task performance differentially from performing a working memory task alone or under overt evaluative threat and, further, whether trait FNE interacts with context to influence performance. Given that task difficulty was expected to moderate these effects (i.e., SET-related task interference may be more pronounced during difficult tasks), two n-back difficulty levels were included in the study design. The primary purpose of this study was to test the feasibility of this manipulation and to inform possible design changes to implement for Study 2. To this end, two different random effects structures were compared: a maximally-specified structure to protect against Type I error and a random intercept-only model to improve power.

The results of Study 1 suggest that social context condition, task difficulty, and FNE interact to influence working memory RT performance, largely in the directions predicted by the default network interference model of SET. The predicted pattern emerged primarily during 3-back trials, the more difficult n-back level, as expected given evidence that working memory disruptions might be more evident during difficult tasks. Of note, while socially anxious individuals exhibited longer RTs during Threat in 3-back trials, they did not display better accuracy; indeed, FNE, whether by itself or in interactions with condition and n-back level, did not correspond with any differences in accuracy. In support of attentional control theory, this suggests that social anxiety confers impairments in efficiency rather than effectiveness. Interestingly, we observed that, rather than impairing accuracy, the Threat condition predicted *greater* accuracy. It is possible that the experience of concurrent SET motivated participants to exert more effort in order to perform well. This possibility will be explored further in Study 2.

Of note, we did not find performance differences between the Presence and Anonymous conditions in the maximal model, suggesting that the mere presence of an experimenter may not be sufficient to elicit feelings of SET. Although the maximally-specified model provides the best protection against Type I errors and, in this study, yielded better model fit than the intercept-only model, comparing these two models allows for the examination of effects that could potentially be uncovered under conditions of greater statistical power. Extrapolating from differences in the fully-specified and intercept-only models, Study 1 may have been underpowered to detect RT differences between the Presence and Anonymous conditions based on FNE. Thus, in addition to adding EEG, changes will be made to Study 2 to improve statistical power. Given the difficulty in changing the behavior of the experimenter in the Presence condition without also changing the interpretation of this condition, power for Study 2 will be improved instead by increasing the sample size (from n=61 to n=101) and shortening the length of time spent in each condition to reduce potential habituation effects.

Study 2: Does default network activity mediate interference with working memory by social-evaluative threat?

Participants and recruitment

Participants for Study 2 (n=101) were recruited through the University's psychology participant pool based on their responses to the BFNE-S (straightforward-worded items only; see description in Study 1), administered as part of the department-wide pre-selection survey. Because sex differences in biological and physiological reactivity to SET have been reported (Kirschbaum, Wüst, & Hellhammer, 1992; Rohleder, Schommer, Hellhammer, Engel, & Kirschbaum, 2001), only women were recruited for Study 2. In addition, all experimenters who ran the study (n=3) were women to prevent potential effects from opposite-sex pairings. Participants were recruited using a stratified sampling method to ensure roughly equal numbers of participants with low, moderate, and high levels of FNE, based on the mean and standard deviation of a previous sample of 1976 college students (*M*=20.55, *SD*=8.14, Rodebaugh et al., 2011). Low levels were defined as scores less than 1 *SD* below the mean of the Rodebaugh et al. sample (<12.41), moderate levels as those between -1 and +1 *SD* (12.41-28.69), and high levels as scores greater than 1 *SD* above the mean (>28.69). Specifically, BFNE-S scores were examined halfway through recruitment and again at the end of each subsequent week, and eligibility was restricted to individuals with low, moderate, or high BFNE-S scores in the participant pool as needed.

Social context manipulation

The social context manipulation in Study 1 was administered nearly identically in Study 2: participants performed the n-back task under three conditions, "Anonymous," "Presence," and "Threat," with order counterbalanced across participants, and measures of state affect were collected after each condition. Changes—elaborated on below—were made to the n-back task and the state measures collected to improve study design and to examine state correlates that more closely map on to hypotheses regarding internal attention.

Materials

Assessment of working memory: Visual n-back task. The n-back task was administered as in Study 1; however, the bars indicating whether the participant's answer was correct or incorrect were removed from each trial. Awareness of one's errors can elicit changes in task behavior and neural activity that could alter the interpretation of frontal theta activity identified in this study (e.g., Trujillo & Allen, 2007). By removing overt information about a participant's performance, we are better able to examine *condition* effects on frontal theta that are less influenced by individual performance.

Additionally, the number of trials and blocks per condition was changed in Study 2. Study 1 revealed that performance changed over time within conditions, such that RTs were likely to be faster (particularly on 3-back trials) and accuracy was likely to be lower (particularly on 2-back trials) on later blocks (data not shown). These performance changes may represent habituation, practice effects, or decreased motivation, which could mask differences between conditions. To reduce this possibility, the number of blocks per condition was reduced from eight alternating blocks of 2-back and 3-back trials to six. To maintain sufficient numbers of trials, trial number was increased to 22 in 2-back blocks and 23 in 3-back blocks. After removing two blocks from the beginning of each 2-back trial and three blocks from the beginning of each 3-back trial from analysis (because these trials cannot be target trials), there were 60 trials of 2-back and 60 trials of 3-back within each condition, for a total of 120 trials per condition (compared to 144 trials per condition in Study 1). Thus, the total time analyzable for EEG was 5.6 minutes for each condition, or 2.8 minutes for each n-back level within each condition.

State responses to social context manipulation. Following each of the three social context conditions, participants were asked to complete items assessing state measures. Because responses to state measures using a 0-100 scale from Study 1 revealed highly skewed and/or bimodal distributions, all state measures for Study 2 were presented using a 5-point Likert scale with 1="Not at all" and 5="Very much." Questions similar to Study 1 were included but were expanded to more precisely define self-reported experience of each condition as well as to include measures that are predicted to be correlates of default network activity. Questions included: “Did you feel alone?”, “Did you feel observed by the experimenter?”, “Did you feel like your task performance was being evaluated?”, “How much did you attend to thoughts or images unrelated to the task?”, “Were you putting effort toward the task?”, “How anxious did you feel?”, “Did you feel negatively evaluated?”, and “Were you sleepy during the task?”

EEG recording. Tin electrodes in a 32-channel stretch-lycra cap were used to record EEG at sites FP1, FP2, F7, F8, F3, F4, Fz, FT7, FT8, FC3, FC4, FCz, T7, T8, C3, C4, Cz, TP7, TP8, CP3, CP4, CPz, P7, P8, P3, P4, Pz, O1, O2, & Oz. All sites were acquired with an online reference site immediately posterior to Cz and subsequently referenced offline to the average of linked mastoids. Electrode impedances were kept under 10 kΩ. All sites were amplified by a factor of 2816 with AC differential amplifiers (bandpass 0.1–300 Hz) and digitized continuously at 1000 Hz. Four electrodes channels were used to monitor electrooculogram (EOG) activity for eye movements, with one electrode placed below the left eye at approximately 10% of the nasion-inion distance in line with the pupil, another placed directly above the left eyebrow, and two other electrodes placed on the outer canthi, also in line with the pupil. Signal processing was conducted using Matlab and EEGLAB, a free plugin for Matlab (Delorme & Makeig, 2004). After data collection, a 1-50Hz band-pass filter was applied to the data to remove gradient artifacts and low frequency noise.

Construction of EEG theta regressor. To isolate frontal theta activity from other sources of theta activity and EEG artifacts, infomax independent component analysis (ICA; Bell & Sejnowski, 1995) was applied to each individual's EEG data across conditions (see Scheeringa et al., 2008) using the *runica* algorithm in EEGLAB. For each participant, the component that best matched the fronto-central scalp distribution of theta components (4-8Hz band at approximately Fz) previously reported by studies that have used ICA to separate frontal theta from other components was used (Makeig et al., 2002; Onton et al., 2005; Scheeringa et al., 2008). A time-frequency analysis of power was applied to the time series of the selected component, with average power from 4-8Hz extracted for each trial. This resulted in 120 trials of frontal theta data for each condition, or 360 trials of frontal theta data for each participant.

Trait questionnaires. The BFNE-S was administered as a prescreening measure in the University participant pool to recruit a stratified sample of participants with low, moderate, and high levels of FNE, as described above. The BFNE-S was collected again at the time of the study to be used as the trait measure of social anxiety in the primary analyses. The BFNE-S showed excellent reliability in this sample (Cronbach's alpha=.94).

As in Study 1, the DASS-D and STICSA were administered during the lab study to examine the unique contribution of social anxiety to working memory performance after controlling for depression and general anxiety symptoms. These scales showed good reliability in this sample (DASS-D: Cronbach's alpha=.85; STICSA: Cronbach's alpha=.90).

Procedure

Upon arrival to the laboratory, participants were informed that they would be completing several rounds of a memory task while physiological measures were recorded and would then complete some questionnaires assessing personality characteristics. Information regarding the different social-contextual conditions was not provided until the end of the experiment.

Following informed consent, participants were attached to EEG and heart rate equipment (heart rate data not reported here) and completed a brief 40-trial practice version of both the 2-back and 3-back task to ensure comprehension. After this, participants performed the n-back task again under the three social context conditions (Anonymous, Presence, and Threat), with condition order counterbalanced across participants. Each condition began with a 20-s "resting state" period in which participants simply observed a fixation cross. EEG was continuously recorded during each condition. State measures were collected immediately following each condition. After completion of the social context manipulation, participants completed a battery of questionnaires assessing levels of several facets of social anxiety, as well as general anxiety and depressive symptoms. Questionnaires were administered last in the study to prevent priming of social anxiety constructs prior to the social context manipulation. Finally, participants were debriefed and received course credit for their participation.

Plan for analyses

Sample size considerations. As with Study 1, straightforward sample size recommendations for multi-level models are not available. Although a significant three-way interaction was found in Study 1 when using either the maximal model or the random intercept-only model, the predicted differences between the Presence and Anonymous conditions only emerged in the random intercept-only model. As such, Study 1 may have been underpowered to detect this effect with the maximal model. To increase power for Study 2, the sample size was increased from n=61 to n=101.

Data scoring and reduction. The BFNE-S, DASS-D, and STICSA were scored by summing across all items, following scoring procedures described in the original publications, and were grand mean-centered for subsequent analyses. For n-back data analysis, trials were excluded from final data analysis if participant RT was less than 200 ms (.5%). All resulting trials were used for analysis of accuracy data. For analysis of RTs, only trials in which participants made a correct response were used (82.6%).

<u>Replication analyses</u>

Interactive effects of social anxiety and social context on working memory performance. To examine the role of trait FNE and social context condition on working memory performance, linear mixed models were conducted for each performance outcome variable (RT and accuracy) using the maximal models described in Study 1 to reduce the possibility of Type I error. As before, fixed effects included n-back difficulty (two levels: 2-back and 3-back), condition (three levels: Anonymous, Presence, and Threat) and FNE (continuous BFNE-S scores). Random effects for the RT model included random by-participant slopes for condition, n-back level, and the interaction between condition and n-back level, a random intercept for participant, and random intercepts for block and trial nested within block. Random effects for the accuracy model included a random by-participant slope for condition. As before, accuracy had a binomial distribution, so a generalized linear mixed model with a binomial link was used. The models were specified in R as:

```
RTs ~ nback*condition*FNE + (condition*nback|ptp) + (1|block/trial)
```

and

```
Accuracy ~ nback*condition*FNE + (condition|ptp)
```

Post-hoc tests were conducted to determine differences in slopes based on condition and n-back level. For post-hoc tests, condition was coded using Helmert contrasts to compare Presence to Anonymous and Threat to Presence and Anonymous. This coding was selected to reduce the number of post-hoc tests from three pairwise tests to two, based on evidence from Study 1 indicating that our primary contrast of interest is between Threat and non-Threat (Presence and Anonymous). N-back level was coded with simple contrasts, in which the intercept is the grand mean. Finally, unstandardized regression coefficients (*b*) are reported in the text; effect sizes, reported as standardized regression coefficients (β), can be found in the tables.

Primary analyses

Moderated mediation of SET-induced performance interference by EEG frontal theta activity. Of primary interest in Study 2 was testing the default network interference hypothesis of SET: whether activity in the default network mediates the interactive effect of social context and trait FNE on working memory performance. To this end, moderated mediation models were conducted using the *mediation* package in R (Tingley, Yamamoto, Hirose, Keele, & Imai, 2014). Mediation tests whether the effect of a variable x on y (total effect; c path) is mediated through an intervening variable m. This pathway from x to m (the a path) and m to y (the b path) is called the indirect effect and can be quantified as $a*b$. The traditional causal steps method (Baron & Kenny, 1986) determined mediation by evaluating whether the effect of x on y becomes less significant after accounting for the indirect effect (called the *direct effect* of *x* on *y*, or *c*'); however, this method has several shortcomings (e.g., Zhao, Lynch, & Chen, 2010). Modern mediation can be determined by testing the significance of the indirect effect, with significance indicating the indirect effect is consistent with mediation (Zhao et al., 2010). *Moderated* mediation, then, occurs when the indirect effect of *x* on *y* depends on levels of a moderator; this can similarly be determined by testing the significance of the indirect effect at various levels of the moderator. Finally, when the sign of the direct effect (*c*') is the same as the sign of the indirect effect (*a***b*), this is called "consistent mediation" or "complementary mediation"; when the signs differ, this is called "inconsistent mediation" or "competitive mediation." Competitive mediation indicates that although an indirect effect of *x* on *y* has been found, there are one or more unaccounted-for *complementary* mediators (opposite in sign to the competitive mediator) that lead to a net effect of *x* on *y* that differs in sign from the competitive indirect path (MacKinnon, Fairchild, & Fritz, 2007; Zhao et al., 2010); this is statistically identical to a suppression effect. For example, we found in Study 1 that SET predicted *improved* accuracy, yet we have hypothesized in Study 2 that SET will reduce frontal theta and that frontal theta will increase accuracy. This hypothesized negative indirect pathway is opposite in sign—and indeed in overall effect—to the positive direct effect of SET on accuracy found in Study 1. Put another way, we hypothesize if SET is found to increase accuracy again in Study 2, that SET will indirectly limit its own positive effect through decreasing frontal theta.

For this study, the statistical models were set up as displayed in Figure 5, in which the predicted effect of SET on impairing working memory performance (i.e., increasing RTs and/or decreasing accuracy) was hypothesized to be mediated by a reduction in frontal theta power, suggesting reduced suppression of default network activity. This threat-related reduction in frontal theta was hypothesized to be greater for individuals higher in trait social anxiety, measured by FNE, due to their greater sensitivity to SET. Additionally, n-back difficulty was anticipated to moderate the effect of default network activity on working memory performance, such that default network interference (indexed as poorer performance as a result of reduced frontal theta) may only be evident, or may be more pronounced, at higher task difficulty. Separate tests were performed for each performance variable (RTs and accuracy), and the significance of indirect effects was tested using 95% confidence intervals derived from 500 quasi-Bayesian Monte Carlo simulations (Imai, Keele, & Tingley, 2010). Again, Helmert contrasts were used to compare Presence to Anonymous and Threat to Presence and Anonymous.

<u>*Secondary analyses*</u>

Moderated mediation of SET-induced performance interference by self-reported effort. In Study 1, we unexpectedly found that Threat improved accuracy. As discussed in Study 1, it is possible that participants exerted greater effort when experiencing concurrent SET, leading to better overt performance. If this association is again found in Study 2, and if frontal theta mediates a negative effect of Threat on accuracy as predicted, this will suggest that competitive mediation has occurred (i.e., the direction of the indirect effect is opposite to that of the direct effect). Competitive mediation would imply the presence of one or more additional complementary mediators leading to the net positive effect of Threat on accuracy. Thus, if this pattern is observed, we will examine self-reported effort as a potential complementary mediator of the effect of condition on RTs and accuracy.

<u>*Supplementary analyses*</u>

As in Study 1, we ran several analyses assessing the effects of depression, trait anxiety, and condition order on frontal theta and/or performance (because we only recruited women for

Study 2, we were unable to look at gender as a moderator). To assess whether effects of FNE on performance were unique to FNE, depression scores from the DASS-D and trait anxiety scores from the STICSA were each included as covariates in the mixed models described above predicting RTs and accuracy. To assess effects of condition order on performance, separate mixed models were conducted for RTs and accuracy with condition, condition order, and their interaction as fixed effects. Random effects included a random by-participant slope for condition order. Condition itself could not be included as a random slope with condition order due to lack of convergence.

We examined several models to rule out alternative interpretations of our data. Because we previously identified effects of condition order on performance, and frontal theta is hypothesized to be related to performance, we tested the effect of condition order on frontal theta. A mixed model was conducted predicting frontal theta from condition, condition order, and their interaction. Random effects included a random by-participant slope for condition order. Condition itself could not be included as a random slope with condition order due to lack of convergence. Because frontal theta has been shown to increase leading to and following recognition of errors, we wanted to determine if frontal theta increased before or after errors, as this would alter the interpretation of heightened frontal theta in this study. Mixed models were conducted predicting frontal theta from condition, pre- or post-error trials (vs. all other trials), and their interaction, with random effects including random by-participant slopes for condition, pre- or post-error trials, and their interaction. To assess whether self-reported mind wandering altered performance, we tested whether answers to the item, “How much did you attend to thoughts or images unrelated to the task?”, either alone or when interacting with condition, predicted RTs or accuracy, with random effects including a random by-participant slope for condition.

Study 2 Results

Participant characteristics

Characteristics of our sample are reported in Table 3. Participants reported levels of FNE on the BFNE-S (*M*=25.17, *SD*=8.08) slightly higher than both the sample from Study 1 and previous university student samples (Rodebaugh et al., 2011), despite recruiting a stratified sample based on the mean and standard deviation of an undergraduate student sample used in Rodebaugh et al (2011).

Manipulation check: State measures

To evaluate whether the social context manipulation had the intended effects on participants, differences among state measures were assessed (Figure 6). As predicted, participants reported monotonic decreases in feelings of being alone and increases in feelings of being observed from the Anonymous to Presence to Threat condition ($ps<.05$). Participants reported less sleepiness, greater effort, greater anxiety, greater feelings of being evaluated, and greater feelings of being negatively evaluated in the Threat condition compared to the Presence and Anonymous conditions ($ps<.05$), indicating our SET manipulation worked as intended (the Presence and Anonymous conditions did not differ from each other on these measures). Interestingly, mind wandering increased from the Threat to Anonymous to Presence condition ($ps<.05$).

Replication analyses: Interactive effects of social context, n-back difficulty, and trait fear of negative evaluation on working memory performance

To attempt to replicate findings from Study 1, the interactive effects of social context condition, FNE, and n-back difficulty level on both RTs for correct trials and accuracy were assessed using mixed effects models. Only the maximal models are described here due to their optimal model fit (Barr et al., 2013). Results are displayed in Table 4.

Reaction times

A significant main effect of n-back level on RTs emerged ($F(1, 6)=8.27$, $p=0.027$), such that participants were slower to respond to 3-back trials compared to 2-back trials ($b=.055$, $SE=.019$, $t(6)=2.88$, $p=.027$). A significant main effect of condition on RT emerged ($F(1, 99)=5.45$, $p=0.006$), such that RTs were longer during Threat compared to Anonymous and Presence ($b=.010$, $SE=.003$, $t(98)=3.30$, $p=.001$), but RTs did not differ between Anonymous and Presence ($b=.0002$, $SE=.006$, $t(99)=.03$, $p=.979$). A two-way interaction between n-back and FNE emerged ($F(1, 99)=4.65$, $p=0.033$), indicating that greater FNE corresponded with longer RTs during 3-back trials compared to 2-back trials ($b=.002$, $SE=.001$, $t(99)=2.16$, $p=.033$). Similar to Study 1, a non-significant two-way interaction between condition and n-back level trended toward significance ($F(2, 97)=2.59$, $p=0.080$). Unlike Study 1, however, no significant three-way interaction was found ($F(1, 97)=.42$, $p=0.659$). Thus, as in Study 1, we found that individuals were slower overall during Threat and that individuals high in FNE showed slower RTs during harder trials, but we did not replicate differences in RTs for high FNE individuals based on condition.

Accuracy

When predicting accuracy, significant main effects of n-back level and condition emerged, indicating that accuracy was lower in 3-back compared to 2-back trials ($b=-.678$, $SE=.029$, $z=-23.05$, $p<.0001$) and was higher in the Threat condition compared to the Presence and Anonymous conditions (*b*=.046, *SE*=.014, *z*=3.29, *p*=.001). Accuracy did not differ between Presence and Anonymous (*b*=.013, *SE*=.022, *z*=.58, *p*=.562). Unlike Study 1, no significant interaction between condition and n-back level emerged (*p*>.05). As in Study 1, FNE did not moderate any effects of condition or n-back level on accuracy, nor was the three-way interaction between FNE, condition, and n-back significant (*p*s>.05). Thus, we again find a positive effect of Threat on accuracy, but unlike Study 1, this was seen across both n-back levels rather than only in 2-back trials.

Primary analyses: Indirect effects of social context on working memory performance through frontal theta

A primary goal of Study 2 was to test whether social context exerted effects on working memory performance through an indirect effect on frontal theta. To help in interpreting indirect effects, we first examined each individual indirect path (*a* path=condition predicting frontal theta; *b* path=frontal theta predicting RTs/accuracy) before testing the significance of the total indirect effect (*a***b*).

<u>*Reaction times*</u>

In examining the *a* path, Presence did not differ from Anonymous in predicting frontal theta (*b*=-.002, *SE*=.009, *t*(98)=-.23, *p*=.819; Table 5); however, Threat predicted reduced frontal theta compared to Anonymous and Presence (*b*=-.036, *SE*=.006, *t*(98)=-6.29, *p*<.0001). In examining the *b* path, higher frontal theta predicted longer RTs (*b*=.020, *SE*=.003, *t*(27230)=7.15, *p*<.0001; Table 4). The indirect effect of frontal theta on RTs was not significant when comparing Presence to Anonymous (*b*=-.0002, *p*=.730, 95% CI [-.001, .0006]) but was significant when comparing Threat to Anonymous and Presence, (*b*=-.002, *p*<.001, 95% CI [-.003, -.001]). This suggests that Threat (compared to non-Threat) may have reduced RTs through an indirect effect on reducing frontal theta (Figure 7A). Because the indirect effect of Threat on RTs through frontal theta was negative but the direct effect of Threat on RTs was positive, this indicated what is called competitive mediation (Zhao et al., 2010) or inconsistent mediation (MacKinnon et al., 2007). In other words, although the net effect of Threat resulted in increased RTs overall, Threat also reduced RTs indirectly through a reduction in frontal theta. This implies the existence of one or more consistent mediators (i.e., indirect effects that have the same sign as the direct effect) that resulted in a net positive effect of Threat on RTs; this led to the secondary analyses of effort as a mediator.

<u>*Accuracy*</u>

Again we first examined the *a* and *b* paths. As mentioned above, Threat predicted reduced frontal theta compared to Anonymous and Presence; Anonymous and Presence did not differ in predicting frontal theta. Overall, higher frontal theta predicted greater accuracy (b=.096, SE=.022, z=4.139 p<.0001; Table 6). When comparing Presence to Anonymous, the indirect effect of frontal theta on accuracy was not significant (b=-.00002, p=.920. 95% CI [-.0005, .0005]). When comparing Threat to Anonymous and Presence, the unstandardized indirect effect was significant (b=-.002, p<.001, 95% CI [-.003, -.001]), consistent with mediation (Figure 7B). As with RTs, this indicated competitive mediation, in which Threat reduced accuracy through an indirect negative effect on frontal theta while having a net positive effect on accuracy as a result of one or more consistent mediators not yet accounted for.

Primary analyses: Moderation of indirect effect of frontal theta by FNE and n-back difficulty level

We next examined whether FNE or n-back level moderated the indirect effects of condition on working memory performance through frontal theta. Specifically, we hypothesized that FNE would increase the effect of Threat on reducing frontal theta (the *a* path) and that n-back difficulty would increase the effect of frontal theta on performance (the *b* path). To examine this, we tested moderation of the *a* and *b* paths by FNE and n-back difficulty level, as displayed in Tables 5 and 6. Where significant individual path moderation by FNE and/or n-back level existed, we tested the significance of the indirect effect ($a*b$) at low (-1 *SD*), moderate (mean), and high (+1 *SD*) levels of FNE and/or low (2-back) and high (3-back) levels of n-back difficulty.

Reaction times

Examination of path moderation indicated that neither the *a* path nor the *b* path was moderated by FNE or n-back difficulty level; thus, the negative indirect effect of condition on RTs through frontal theta did not differ based on FNE or n-back difficulty level. However, as discussed above, RTs were moderated by a two-way n-back level by FNE interaction, irrespective of levels of frontal theta (Figure 7A).

Accuracy

Examination of path moderation indicated that the *a* path was not moderated by FNE or n-back difficulty level. However, the *b* path (the effect of frontal theta on accuracy) was moderated by both n-back difficulty level and by n-back difficulty x FNE, as depicted in Figure 7B. In other words, a two-way frontal theta x n-back level interaction predicting accuracy was subsumed by a three-way frontal theta x n-back level x FNE interaction. To decompose this interaction, we first examined the interaction between frontal theta and FNE within each n-back difficulty level (2-back and 3-back). Frontal theta and FNE did not interact during 2-back trials (b=.002, SE=.003, z=.61, p=.541) but did interact during 3-back trials (b=-.007, SE=.003, z=-2.19, p=.029). This interaction indicated that during harder trials, the positive effect of higher frontal theta on accuracy decreased as FNE increased (Figure 8). Thus, individuals higher in FNE displayed less of a benefit to accuracy from increased frontal theta during harder trials. We additionally decomposed this interaction by examining the interaction between frontal theta and n-back level at low, moderate, and high levels of FNE. The positive effect of frontal theta on accuracy was greater during 3-back trials compared to 2-back trials at low (b=.135, SE=.038, z=3.55, p<.001) and moderate (b=.064, SE=.025, z=2.57, p=.010) levels of FNE but did not differ based on n-back level at high levels of FNE (b=-.008, SE=.033, z=.23, p=.818). In other words, frontal theta was especially beneficial for improving accuracy when the task was more difficult, except for individuals high in FNE.

Because we found significant moderation of the *b* path by FNE and n-back level, we tested the significance of the indirect effect (a*b) at low (-1 *SD*), moderate (mean), and high (+1 *SD*) levels of FNE and at low (2-back) and high (3-back) levels of n-back difficulty (Table 7). We found that when comparing the Threat condition to the Presence and Anonymous conditions, a significant indirect effect of frontal theta was found across all combinations of FNE and n-back level (all *p*s<.05) except in those low in FNE during 2-back trials (b=-.0007, p=.140, 95% CI [-.0019, .0003]). This suggests that when trials are easier and the individual is low in FNE, Threat does not reduce accuracy via a reduction in frontal theta. This supports our hypothesis that reduced working memory performance via reduced frontal theta would be especially evident as task demands increase (e.g., when an individual is higher in FNE or when the task itself is more difficult).

Secondary analyses: Indirect effects of social context on working memory performance through effort

Intriguingly, our previous analyses showed that participants displayed longer RTs and greater accuracy during Threat compared to Presence and Anonymous, despite Threat leading to a reduction in frontal theta (of which greater levels also predicted longer RTs and greater accuracy). It is possible that participants engaged in compensatory behaviors during Threat that improved accuracy but led to longer RTs, overcoming the overt negative performance effects of reduced frontal theta. To examine this, we tested the hypothesis that participants performed more slowly and accurately during Threat compared to Presence and Anonymous through an indirect effect on effort. We used the single self-report item assessing perceived effort following each condition as our measure of effort. We first examined each individual indirect path (*a* path=condition predicting effort; *b* path=effort predicting RTs/accuracy) before testing the significance of the total indirect effect ($a*b$).

Reaction times

In examining the *a* path, Threat predicted greater effort compared to Anonymous and Presence (b=.134, SE=.024, $t(198)$=5.67, p<.0001; Table 8). In examining the *b* path, effort predicted longer RTs (b=.041, SE=.008, $t(230)$=5.24, p<.0001; Table 9). The unstandardized indirect effect ($a*b$) was significant when comparing Threat to Presence and Anonymous, (b=.012, p<.01, 95% CI [.007, .018]), indicating Threat increased RTs indirectly through increased perceived effort (Figure 9A).

Accuracy

As above, Threat predicted greater effort compared to Anonymous and Presence (the *a* path). In examining the *b* path, effort predicted greater accuracy (b=.175, SE=.031, z=5.62, p<.0001). When comparing Threat to Anonymous and Presence, the unstandardized indirect effect was significant (*b*=.008, *p*<.01, 95% CI [.004, .013]), indicating Threat increased accuracy indirectly through increased perceived effort (Figure 9B).

Secondary analyses: Moderation of indirect effect of effort by FNE and n-back level

We next examined whether FNE or n-back level moderated the indirect effects of Threat on working memory performance through effort. As before, we tested moderation of the *b* path by FNE and n-back difficulty level; only FNE was tested as a moderator of the *a* path because self-reports of effort were only taken at the end of each condition and thus did not differ by n-back level. Where significant individual path moderation by FNE and/or n-back level existed, we tested the significance of the indirect effect (*a***b*) at low (-1 *SD*), moderate (mean), and high (+1 *SD*) levels of FNE and/or low (2-back) and high (3-back) levels of n-back difficulty.

Reaction times

Examination of path moderation indicated that neither the *a* path nor the *b* path was moderated by FNE or n-back difficulty level (Tables 8 & 9); thus, the indirect effect of condition on RTs through effort did not differ based on FNE or n-back difficulty level. However, the *b* path (the effect of effort on RTs) showed a non-significant trend toward being moderated by FNE and n-back difficulty (*b*=-.002, *SE*=.001, *t*(216)=-1.93, *p*=.054 and *b*=.012, *SE*=.007, *t*(267)=1.88, *p*=.062, respectively). These trends suggested that individuals higher in FNE showed less of an increase in RTs as a result of effort and that effort increased RTs more during harder 3-back trials.

Accuracy

Examination of path moderation indicated that the *a* path was not moderated by FNE or n-back difficulty level (Table 8). However, the *b* path (the effect of effort on accuracy) was moderated by n-back level (Table 9). This interaction between effort and n-back level indicated that greater effort improved accuracy less during 3-back compared to 2-back trials (b=-.116, SE=.026, z=-4.38, p<.0001). Although not significant, a three-way interaction between effort, n-back difficulty, and FNE showed a non-significant trend toward significance (b=-.006, SE=.003, z=-1.94, p=.052). This trend suggested that during harder 3-back trials, greater effort was less effective at improving accuracy in individuals high in FNE compared to individuals low in FNE.

Because we found significant moderation of the *b* path (the effect of effort on accuracy) by n-back level, we tested the significance of the indirect effect (*a***b*) at low (2-back) and high (3-back) levels of n-back difficulty. We found that when comparing the Threat condition to the Presence and Anonymous conditions, a significant indirect effect of effort was found at both n-back levels but was greater during 2-back trials (b=.009, p<.01, 95% CI [.006, .012]) than during 3-back trials (b=.005, p<.01, 95% CI [.001, .009]). Thus, the indirect effect of Threat on accuracy through effort was greater during easier trials.

Supplementary analyses

Several additional analyses were performed to provide a more thorough understanding of our results and to assess possible alternative explanations for our findings.

Depression and trait anxiety. As seen in Table 3, participants reported levels of depression (using scores from the DASS-D) and trait anxiety (using scores from the STICSA) in line with norms from previous undergraduate student samples (Lovibond & Lovibond, 1995; Ree et al., 2008). When including depression or trait anxiety as covariates in models predicting RTs or accuracy from condition, n-back level, and FNE, the pattern of significance did not change, indicating the effects of FNE on RTs and accuracy held after controlling for depression and trait anxiety.

Condition order effects. Because of the within-subjects design of this study, practice or fatigue may have affected performance and/or brain activity over time. We conducted separate models to determine whether condition order interacted with condition and FNE to influence RTs, accuracy, and frontal theta. As in Study 1, condition order showed a main effect on RTs and accuracy such that RTs were faster and accuracy was higher on each subsequent condition ($ps<.05$), suggesting practice effects (improved performance) rather than fatigue effects (reduced performance) over time. FNE and condition did not interact with condition order to predict RTs or accuracy ($ps>.05$), indicating that individuals showed similar improvements in performance over time regardless of FNE or particular condition order. Frontal theta did not change over time, either by itself or when interacting with FNE or condition ($ps>.05$).

Error-related frontal theta. Frontal theta has been shown to increase in relation to awareness of making an error (Cavanagh, Frank, Klein, & Allen, 2010; Luu, Tucker, & Makeig, 2004). Although this study did not provide feedback to participants regarding their accuracy, we wanted to check if frontal theta was heightened before and/or after errors to aid in interpretation of the role of frontal theta in this study. Frontal theta was lower on trials immediately prior to and immediately following errors compared to all other trials ($F(1, 110)=11.81$, $p<.001$ and $F(1, 108)=43.35$, $p<.0001$, respectively), suggesting increased frontal theta was not related to awareness of errors. Further, error-related changes in frontal theta did not differ by condition ($ps>.05$).

Performance, frontal theta, and mind wandering. Because higher default network activity has been associated with mind wandering (Andrews-Hanna, 2012), we wanted to examine whether self-reports of mind wandering corresponded with differences in performance or frontal theta. To do so, we tested whether answers to the item, “How much did you attend to thoughts or images unrelated to the task?", predicted RTs, accuracy, or frontal theta either as a main effect or when interacting with condition. Self-reported mind wandering predicted faster RTs irrespective of condition ($F(1, 221)=14.99$, $p=.0001$) but did not predict differences in accuracy, by itself or when interacting with condition (ps>.05). Mind wandering also did not predict differences in frontal theta, by itself or when interacting with condition (ps>.05).

Discussion

Several lines of research have shown that social-evaluative threat (SET) disrupts performance, which is hypothesized to be related in part to a diversion toward self-focused thoughts (Beilock et al., 2007; Heimberg et al., 2010). The primary goal of this dissertation was to test the default network interference hypothesis of SET as a mechanism for this disruption—that difficulty suppressing the default network, a collection of brain regions related to self-focused thought, mediates the detrimental effects of SET on performance, and further, that task difficulty and social anxiety increase interference by the default network. To test this, we recruited undergraduates to perform a working memory task, the n-back task, during a novel experimental paradigm intended to differentiate among the effects of being alone (Anonymous), in the presence of the experimenter (Presence), and under explicit evaluation by the experimenter (Threat). In Study 1, we tested and validated this paradigm, and in Study 2, we refined and implemented this paradigm while concurrent EEG was recorded to test the default network interference hypothesis of SET. Frontal theta was selected as our EEG-based neural mediator, as it correlates with suppression of default network activity (Scheeringa et al., 2008, 2009). We found support for SET-related interference by default network activity as indexed by reduced frontal theta, despite the fact that Threat led to an overall increase in accuracy and RTs. Analysis of self-report data showed that participants mobilized extra effort during Threat, leading to better accuracy and longer RTs and suggesting that effort may have helped overcome SET-related reductions in frontal theta. The effects of frontal theta on performance were stronger during harder 3-back trials, except for individuals high in FNE, who showed less benefit from frontal theta during 3-back trials.

Validating a novel experimental paradigm

Studies of the effects of SET on cognitive performance often use tasks involving anticipation of future evaluation to elicit SET. For example, when participants completed an n-back task while anticipating giving a speech, they showed longer RTs and poorer accuracy (Schoofs et al., 2008). Even some instances of stereotype threat may be best conceptualized as threats regarding future evaluation. For instance, a woman exposed to gender stereotypes regarding math performance may focus on the eventual evaluation of her math test after she turns it in, if she is not concurrently being evaluated. Thus, it is not well-understood how concurrent evaluation, by comparison, affects performance. We sought to develop and validate a paradigm comparing completion of a cognitive task in a context of concurrent SET (Threat) to a context without concurrent evaluation in which the participant completed the task alone (Anonymous). Additionally, to avoid conflating effects of SET with effects of social presence and because the presence of an audience may be interpreted as threatening by socially anxious individuals (Heimberg et al., 2010), we included a third condition in which the experimenter was present but not overtly evaluating the participant (Presence).

We found that the Threat condition increased feelings of social presence, anxiety, effort, being observed, general evaluation, and negative evaluation compared to the Presence and Anonymous conditions. Further, Presence elicited greater feelings of social presence and being observed, and, in Study 1, greater feelings of evaluation and anxiety than the Anonymous condition. Interestingly, in Study 2, evaluation and anxiety did not differ between the Anonymous and Presence conditions, perhaps due to differences in study design discussed in greater detail below. Nevertheless, as intended, we found that the Threat condition elicited greater feelings of evaluative anxiety than the two non-Threat conditions and that the Presence condition elicited feelings of social presence that were greater than the Anonymous condition, providing validation that our social context manipulation worked as intended.

How do social-contextual factors influence working memory performance?

Based on prior research on the effects of anticipatory SET, we hypothesized that our Threat condition would impair performance through reducing accuracy and lengthening RTs. In both studies, we found that while Threat increased RTs as anticipated, it also led to *greater* accuracy, indicating that SET may improve effectiveness (accuracy) at the expense of efficiency (RTs). While attentional control theory suggests that anxiety may impair efficiency more so than effectiveness (Eysenck, Derakshan, Santos, & Calvo, 2007), a finding of *increased* effectiveness, rather than no effect or decreased effectiveness, is not often reported in SET literature. This unexpected result may be because, as mentioned above, we examined the effects of concurrent evaluation, rather than only anticipatory evaluation, on performance. Concurrent evaluation may increase pressure to perform well on the current task, as the threat lies in the present situation rather than in one's future evaluation. Further, while concurrent evaluation improved overt performance (in terms of accuracy), it reduced how quickly each trial was answered, suggesting that SET induced a less efficient, more careful responding style. It is worth pointing out that the motivation to perform well may be especially high in undergraduate participants, perhaps even more so when being evaluated by similarly-aged peers (i.e., the research assistants administering the study protocol), as was the case in our studies. Future studies may wish to examine whether concurrent evaluative threat similarly improves performance accuracy in a non-student sample.

Contrary to our hypotheses, the presence of an experimenter did not change working memory performance compared to being alone, even in individuals high in FNE. It is possible that the mere presence of another person simply did not elicit sufficient anxiety in our studies to be disruptive. Indeed, while participants reported greater anxiety and evaluation during the Presence condition compared to the Anonymous condition in Study 1, no such differences were observed in Study 2. This may be due to changes to the n-back task between the two studies: in Study 1, the n-back task provided visual feedback about the participant's accuracy, which was removed in Study 2. Thus, it may be that in Study 1, the *potential* for the experimenter to evaluate the participant's performance during the Presence condition is what led to an increase in anxiety and feelings of evaluation, which was nevertheless insufficient to yield differences in performance outcomes. The distinction between social presence with and without potential evaluation is worth exploring in future studies.

Does the default network mediate performance interference?

The primary goal of these studies was to test the default network interference hypothesis of SET: that SET leads to poorer working memory performance due to an indirect effect on reducing suppression of default network activity, as default network activity is thought to represent increased attention to internal, task-irrelevant stimuli. We examined frontal theta as an EEG correlate of suppression of default network activity and found that it mediated performance interference by SET. As predicted, the Threat condition reduced activity in frontal theta (implying less suppression of default network areas). This in turn reduced the positive effect of frontal theta on working memory accuracy, supporting the default network interference hypothesis of SET. Interestingly, frontal theta associated with both increased accuracy and RTs, again suggesting that while it improved effectiveness, it did so at the expense of efficiency. While speed-accuracy tradeoffs are common in psychology (Heitz, 2014), it seems counter-intuitive that successfully suppressing default network activity would lead to increased RTs. One possibility worth exploring in greater detail is that frontal theta and default network suppression correspond with processes in addition to the reduction of internal mentation. Several lines of evidence, discussed in detail below, converge on the hypothesis that frontal theta represents a heightened need for cognitive control across several different contexts.

Frontal theta as an indicator of cognitive control

The relationship between frontal theta and the default network. A critical consideration in interpreting our results is that frontal theta might represent neural processes beyond the suppression of default network activity. We selected frontal theta as our EEG marker of default network suppression based on several studies combining EEG and fMRI that showed negative correlations between frontal theta and activity in default network areas (Meltzer et al., 2007; Michels et al., 2010; Scheeringa et al., 2008, 2009; White et al., 2013; however, see Sammer et al., 2007). Studies using positron emission tomography (PET), low-resolution brain electromagnetic tomography (LORETA), magnetoencephalography (MEG), and dipole source modeling have all localized the source of frontal theta to areas of the medial prefrontal cortex near the dorsal anterior cingulate cortex (dACC; Asada, Fukuda, Tsunoda, Yamaguchi, & Tonoike, 1999; Gevins et al., 1997; Ishii et al., 1999; Onton et al., 2005; Pizzagalli, Oakes, & Davidson, 2003; Sauseng, Hoppe, Klimesch, Gerloff, & Hummel, 2007). The dACC is a key structure in both the cingulo-opercular and salience networks, which are related to alertness and processing of salient sensory information (Sadaghiani & D’Esposito, 2015; Seeley et al., 2007).

These networks often show antagonistic relationships with default network activity (Fox et al., 2005; Uddin et al., 2009), suggesting that frontal theta may reflect top-down modulation of default network activity, rather than direct modulation of the default network itself (Anticevic et al., 2012). Thus, frontal theta is likely to be involved in controlled attention that may be reflected in careful (accurate but slow) responding, as was observed in Study 2.

Frontal theta and errors. Reflecting a role in top-down processing, several researchers posit that one role of frontal theta is establishing cognitive control following errors, citing evidence from event-related potentials (ERPs; Cavanagh & Shackman, 2015; Luu et al., 2004; Trujillo & Allen, 2007). This suggests the possibility that the association we observed between frontal theta and longer RTs may have been due to error trials. However, in Study 2, frontal theta activity actually decreased on trials following errors, indicating that the frontal theta we observed was not error-related. This is likely because Study 2 did not provide feedback to participants regarding their performance. Interestingly, Cavanagh and Shackman (2015) hypothesize that anxious individuals should show *greater* frontal theta responses due to their heightened sensitivity to errors. Yet, we found no evidence that individuals higher in FNE displayed greater frontal theta under any condition, and, on the contrary, found that our anxiety-provoking Threat condition reduced frontal theta, a finding supported by previous research (Gärtner et al., 2015; Gärtner, Rohde-Liebenau, Grimm, & Bajbouj, 2014). Still, the possibility that frontal theta indexes error-related cognitive control in general is not incompatible with our findings. It is possible that increases in frontal theta related to anxiety and errors are transient fluctuations observable with fine-grained temporal analysis of ERPs that were not captured by our analytic strategy and/or study design. In support of this, anxiety has been shown to correspond with reduced sustained but greater transient activity in brain areas related to cognitive control during the n-back task (Braver, 2012). Future examination of SET-related frontal theta activity in both the temporal and spectral domains may help shed light on these inconsistencies.

Frontal theta and task demands. While frontal theta and default network suppression are thought to indicate increased task focus, the circumstances leading to greater suppression of the default network may indicate uncertainty, task difficulty, or fatigue. For example, during a picture recognition task, suppression of default network areas was greater when the pictures were reported as less familiar, and this default network suppression associated with longer RTs (Gimbel & Brewer, 2011), suggesting that greater suppression of the default network indicated less certainty regarding recognition. Further, frontal theta and suppression of default network activity increase with task demands and with fatigue, indicating a greater need to suppress the default network as either objective or subjective task difficulty increases (Gevins et al., 1997; McKiernan, Kaufman, Kucera-Thompson, & Binder, 2003; Nakagawa et al., 2013; Onton et al., 2005). Thus, suppression of the default network (or higher frontal theta) may represent a greater need to focus in the face of uncertainty, fatigue, and increasing task demands. This focus seems likely to result in careful (more effective but less efficient) responding rather than speeded, certain responding, which may explain why frontal theta corresponded with both increased accuracy and increased RTs in our study.

Default network, attention lapses, and performance. Default network activation during attention-demanding tasks is thought to indicate a lack of task focus and, thus, less efficient processing of stimuli. Not surprisingly, then, these default network-related lapses of attention have been shown to associate with longer RTs (Grinband et al., 2011; Hahn et al., 2007). However, lapses of attention may, in some cases, paradoxically reduce RTs. Analysis of RT data during an attention task suggested that a pattern characterized by relatively slow responding that shifted toward faster responding at the end of a block of trials appeared to indicate "zoning out," in which participants began to answer trials more quickly and carelessly (Smallwood, McSpadden, Luus, & Schooler, 2008). Similarly, during an anti-saccade task, greater activation in the default network and faster RTs were found in trials preceding and during errors, purportedly indicating a state of mind wandering that led to the error (Agam et al., 2013). While we did not find that frontal theta was related to mind wandering, we did observe a negative correlation between individuals' subjective reports of mind wandering and their RTs, suggesting that self reports of mind wandering corresponded with faster responding. Thus, slower responding may represent attention to the task, at least on the n-back task used in our studies.

In summary, frontal theta is likely to represent top-down control of default network activity by the dACC, a neural process that generally corresponds with attentional focus and cognitive control. Frontal theta may be more evident during periods in which cognitive control is especially required, such as instances of uncertainty or following errors. This top-down control appears to correspond with a more careful response style characterized by better accuracy but slower RTs, a response style displayed by participants during SET in both Study 1 and Study 2. Social-evaluative contexts may reduce frontal theta, suggesting evaluative anxiety reduces top-down control of default network processes. Anxious individuals may require more effortful cognitive control (indexed by greater frontal theta) to perform as well as less anxious individuals when task difficulty increases, as evidenced by the reduced effect of frontal theta in increasing accuracy in individuals high in FNE in Study 2.

Social anxiety and task difficulty as moderators of performance and default network activity

To further characterize the default network interference hypothesis of SET, we hypothesized that social anxiety (measured as FNE) and task difficulty would moderate the effect of condition on performance through moderating the indirect effect of condition on frontal theta. Specifically, we predicted that FNE would increase the effect of Threat on reducing frontal theta (i.e., individuals higher in FNE would show a greater reduction in frontal theta during Threat due to perceiving the situation as more threatening) and that task difficulty would increase the effect of frontal theta on performance (i.e., higher frontal theta would improve performance more during harder trials, as suppression of default network activity is likely to be more beneficial as task difficulty increases). In support of these hypotheses, we observed that task difficulty moderated the effect of frontal theta on performance in the predicted direction, but only on accuracy. In other words, higher frontal theta improved accuracy more during 3-back compared to 2-back trials.

Surprisingly, FNE did not moderate the effects of condition on frontal theta, indicating that individuals high in FNE experienced the same reduction in frontal theta during Threat as those low in FNE. It is possible that the reduction in frontal theta seen during Threat was the result of processes other than evaluative anxiety, or that the BFNE-S did not capture the construct of evaluative anxiety relevant to participants' experiences during Study 2. However, FNE did moderate the interactive effect of frontal theta and task difficulty on accuracy, such that participants showed improved accuracy as a result of greater frontal theta during harder 3-back trials unless they were high in FNE. In other words, greater suppression of the default network did not boost performance for individuals high in FNE during more difficult trials. While different from our exact predictions, this finding is consistent with the general idea that social anxiety confers performance deficits, in this case indicating a deficiency in benefiting from the putative suppression of default network activity indexed by frontal theta when task difficulty increases. One speculation is that frontal theta, if it signifies top-down control of the default network, acts independently of bottom-up default network activity. If so, it remains possible that socially anxious individuals may still experience interference by default network activity that was not suppressed by frontal theta activity. It is striking that this finding was independent of condition: even when alone, individuals high in FNE were not benefiting from increased frontal theta during harder trials. While this study was not designed to disentangle this finding, it is possible that in more socially anxious individuals, frontal theta represents task focus in the face of greater uncertainty, as discussed above.

Interestingly, in Study 1, task difficulty moderated the effect of condition on accuracy, and task difficulty interacting with FNE moderated the effect of condition on RTs; however, in Study 2, task difficulty and FNE did not moderate the effect of condition on either accuracy or RTs (although task difficulty and FNE predicted RTs independent of condition). This again may be related to the removal of feedback regarding trial accuracy in Study 2, possibly making the threat of evaluation less salient because participants were unaware of their actual performance. The impact of personality variables or task demands on the effects of SET may be more pronounced when participants are able to gauge their performance, either objectively through task feedback or subjectively through self-assessment or interpretations of others' reactions.

The role of compensatory effort on performance

Because we found evidence for competitive mediation by frontal theta (i.e., Threat and frontal theta both increased accuracy and RTs, yet Threat led to reduced frontal theta), we hypothesized that individuals were engaging in more cognitive effort during threat, which led to performance improvements. Follow-up analyses indeed suggested that participants reported exerting greater effort during the Threat condition compared to the non-Threat conditions and that self-reported effort corresponded with slower but more accurate responding. It is possible that effort was mobilized to compensate for the reduction in frontal theta experienced during Threat. However, effort did not correlate with frontal theta, raising the question of whether increased effort was a compensatory response or a response unrelated to decreases in frontal theta. It is worth pointing out that we used a single self-report item following each condition as our measure of effort, which may have limited the measure's reliability and, further, may only reflect perceived effort near the end of each condition, rather than throughout. Previous studies have identified correlations between frontal theta and physiological indicators of effort, such as heart rate variability (Kubota et al., 2001). Therefore, future studies should utilize more objective, ongoing assessments of effort, such as heart rate variability or facial electromyography, in addition to self-report, to assess the relationship between SET, frontal theta, and effort.

Limitations

The findings of these studies should be interpreted in light of several limitations. A primary limitation is that we did not directly test the effects of SET on the default network. As discussed above, we have several reasons to believe that frontal theta corresponds with decreased default network activity, but it may not be a direct relationship. Future studies should test the default network interference hypothesis of SET using fMRI, although it may be more difficult to manipulate the experience of ongoing SET in the fMRI environment.

A second limitation is that it is unclear how our findings might generalize to men. In Study 1, women composed over three-quarters of our sample, and in Study 2, only women were recruited. We elected to recruit only women in Study 2 to reduce variability due to documented differences in how men and women respond to SET (Kirschbaum et al., 1992; Rohleder et al., 2001) and to prevent possible feelings of anxiety from opposite-sex pairings between the participant and experimenter. Because of this, less is known about whether default network interference affects men. However, previous studies have identified differences in default network activity as a result of social anxiety and SET in groups composed of both men and women (Blair et al., 2008; Maresh et al., 2014; van Ast et al., 2014), suggesting default network interference might operate the same in men.

Similarly, a third limitation is that both of our samples were restricted to undergraduate students who were an average of 19 years old. During this developmental period of late adolescence, while basic working memory abilities may be stable (Luciana, Conklin, Hooper, & Yarger, 2005), individuals are still undergoing neural changes, including maturation of networks implicated in working memory and cognitive control (Finn, Sheridan, Kam, Hinshaw, & D'Esposito, 2010; Scherf, Sweeney, & Luna, 2006). Further, fear of social evaluation may peak during this period of time (Westenberg, Gullone, Bokhorst, Heyne, & King, 2007). Thus, individuals in late adolescence may be especially susceptible to default network interference; studies aimed at investigating the developmental trajectory of default network interference could shed light on during what period it is especially problematic.

A fourth limitation is that it may not be possible to totally eliminate feelings of evaluation from an experiment. Although participants were not explicitly evaluated in the Anonymous and Presence conditions, they may have felt evaluation from the application of EEG measures that signify monitoring is occurring (in addition to the implicit evaluation likely to be felt in any psychology study). While this effect was presumably constant across all conditions, thus minimizing impact on the observed condition differences, it is likely that we were unable to capture performance in a purely non-evaluative state.

Finally, we elected to use a within-subjects design to examine how social context condition changes performance within an individual rather than between individuals. Within-subjects designs can lead to practice, habituation, and/or fatigue effects that obscure differences between conditions. Indeed, supplementary analyses in both studies indicated that participants showed faster and more accurate n-back performance on each subsequent condition. However, order effects were minimized through counterbalancing condition order among participants. Additionally, performance improvement over time did not differ based on condition or levels of social anxiety.

Clinical implications and conclusions

These studies sought to expand our understanding of the wide-ranging and pernicious effects of SET. Ironically, SET may improve an individual's overt performance, yet at the expense of efficiency, yielding a subjective increase in effort that may not be sustainable over long periods of time. Given the near-constant presence of others in the activities of the modern human (and thus the near-constant potential to be evaluated), a person's daily life may be more difficult or effortful when there is the potential to perceive SET, even in the absence of actual social interaction. Further, we found that the difficulties conferred by social anxiety are not restricted to social tasks (e.g., giving a speech, holding a conversation)—rather, a socially anxious person's ability to perform may be impaired across a variety of tasks.

A final goal of these studies was to highlight the need for careful consideration and clarity of methodology when designing "neutral" or "baseline" conditions in studies, both with and without socially anxious samples. The presence of an experimenter may have unintended effects on behavior and brain activity, especially if he or she is able to observe the participant's performance. Thus, having the experimenter leave the room if feasible or at least describing the location and behavior of the experimenter during the task (e.g., "The experimenter sat out of eyesight of the participant and could not observe the participant's performance") could aid in interpretation of findings.

Although these studies focused on the role of the default network in impairing working memory performance, default network dysregulation has been linked to cognitive and mood difficulties broadly (e.g., Broyd et al., 2009; Fassbender et al., 2009; Sheline et al., 2009; Sonuga-Barke & Castellanos, 2007). This suggests that the default network interference hypothesis of SET may partially explain several of the detrimental downstream effects of SET, such as negative affect, fatigue, and wide-ranging cognitive difficulties. Clinically, this model could inform research across several disorders related to or exacerbated by social threat, such as test anxiety, mood disorders, eating disorders, or conduct disorders, in addition to social anxiety disorder. Further, default network interference by SET could impact our understanding of several topics relevant to society, including stereotype threat, social status, and intergroup relations.

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Table 1. ANOVA table comparing maximal and intercept-only models predicting reaction times in Study 1. Degrees of freedom are estimated using Satterthwaite approximation.

Fixed effect	**Numerator DF**	**Denominator DF**	**F value**	**P value**
	Maximal model			
FNE	1	59	0.13	0.721
Condition	2	59	0.84	0.436
N-back level	1	23	14.90	**0.001**
FNE x condition	2	59	0.65	0.523
FNE x n-back	1	59	0.69	0.411
Condition x n-back	2	58	2.80	0.069
FNE x condition x n-back	2	58	5.15	**0.009**
	Random intercept-only model			
FNE	1	59	0.11	0.747
Condition	2	22835	9.45	**<.0001**
N-back level	1	6	35.46	**0.001**
FNE x condition	2	22836	9.76	**<.0001**
FNE x n-back	1	22835	11.78	**<.0001**
Condition x n-back	2	22835	4.50	**0.011**
FNE x condition x n-back	2	22835	10.79	**<.0001**

Note. FNE=Fear of negative evaluation.

Table 2. Analysis of deviance table for random slope model predicting accuracy in Study 1.

Fixed effect	**Chi square**	**DF**	**P value**
FNE	0.05	1	0.823
Condition	4.48	2	0.107
N-back	433.32	1	**<.0001**
FNE x condition	1.59	2	0.451
FNE x n-back	0.18	1	0.675
Condition x n-back	20.04	2	**<.0001**
FNE x condition x n-back	1.57	2	0.455

Note. FNE=Fear of negative evaluation.

Table 3. Study 2 participant demographics.

	Total
N (females)	101 (101)
Age *M (SD)*	18.59 (.87)
Race N (%)	
White	74 (73%)
Asian	16 (16%)
Black	4 (4%)
Other/Mixed	7 (7%)
Ethnicity N (%)	
Hispanic	7 (7%)
Non-Hispanic	94 (93%)
BFNE-S *M (SD)*	25.17 (8.08)
DASS-D *M (SD)*	2.41 (2.91)
STICSA *M (SD)*	37.77 (10.42)

Note. BFNE-S=Brief Fear of Negative Evaluation Scale-Straightforward worded items; DASS-D=Depression Anxiety Stress Scales-Depression subscale. STICSA=State-Trait Inventory for Cognitive and Somatic Anxiety-Trait version.

Table 4. Condition, n-back level, and FNE predicting reaction times and accuracy in Study 2.

Predictor	***b***	***SE***	***β***	**Statistical test**	***p***
	Predicting reaction times (*c* path)				
Intercept	0.825	0.023		t(79)=36.59	**<.0001**
Condition					
Presence vs. Anonymous	0.000	0.006	0.001	t(99)=.03	0.979
Threat vs. Presence & Anonymous	0.010	0.003	0.038	t(98)=3.30	**0.001**
n-back (3-back vs. 2-back)	0.055	0.019	0.070	t(6)=2.88	**0.027**
FNE	0.002	0.003	0.049	t(99)=.87	0.389
Condition x n-back					
Presence vs. Anonymous x n-back	-0.007	0.006	-0.008	t(96)=-1.20	0.232
Threat vs. Presence & Anonymous x n-back	0.006	0.003	0.012	t(98)=2.08	**0.040**
Condition x FNE					
Presence vs. Anonymous x FNE	0.000	0.001	-0.004	t(99)=-.32	0.746
Threat vs. Presence & Anonymous x FNE	0.000	0.000	-0.003	t(98)=-.23	0.822
FNE x n-back	0.002	0.001	0.026	t(99)=2.16	**0.033**
Condition x n-back x FNE					
Presence vs. Anonymous x n-back x FNE	0.000	0.001	0.000	t(97)=.06	0.949
Threat vs. Presence & Anonymous x n-back x FNE	0.000	0.000	0.005	t(98)=.90	0.372
	Predicting accuracy (*c* path)				
Intercept	1.687	0.056		z=29.91	**<.0001**
Condition					
Presence vs. Anonymous	0.013	0.022	0.027	z=.58	0.562
Threat vs. Presence & Anonymous	0.046	0.014	0.171	z=3.29	**0.001**
n-back (3-back vs. 2-back)	-0.678	0.029	-0.895	z=-23.05	**<.0001**
FNE	-0.006	0.007	-0.133	z=-.89	0.371
Condition x n-back					
Presence vs. Anonymous x n-back	-0.060	0.026	-0.065	z=-1.69	0.091
Threat vs. Presence & Anonymous x n-back	0.024	0.021	-0.046	z=-1.16	0.247
Condition x FNE					
Presence vs. Anonymous x FNE	0.001	0.003	0.024	z=.53	0.599
Threat vs. Presence & Anonymous x FNE	-0.001	0.002	-0.033	z=-.65	0.516
FNE x n-back	-0.006	0.004	-0.059	z=-1.53	0.125
Condition x n-back x FNE					
Presence vs. Anonymous x n-back x FNE	0.007	0.004	0.060	z=1.56	0.115
Threat vs. Presence & Anonymous x n-back x FNE	-0.002	0.003	-0.028	z=-0.73	0.468

Note. FNE=Fear of negative evaluation.

Table 5. Condition, n-back level, and FNE predicting frontal theta in Study 2.

Predictor	***b***	***SE***	***β***	**Statistical test**	***p***
				Predicting frontal theta (*a* path)	
Intercept	-3.421	0.102		t(103)=-33.54	**<.0001**
Condition					
Presence vs. Anonymous	-0.002	0.009	-0.001	t(98)=-.23	0.819
Threat vs. Presence & Anonymous	-0.036	0.006	-0.044	t(98)=-6.29	**<.0001**
n-back (3-back vs. 2-back)	-0.032	0.040	-0.013	t(5)=-.80	0.466
FNE	-0.010	0.012	-0.070	t(99)=-.83	0.411
Condition x n-back					
Presence vs. Anonymous x n-back	-0.020	0.012	-0.007	t(97)=-1.65	0.102
Threat vs. Presence & Anonymous x n-back	0.007	0.007	0.004	t(94)=1.07	0.288
Condition x FNE					
Presence vs. Anonymous x FNE	0.000	0.001	0.001	t(98)=.23	0.820
Threat vs. Presence & Anonymous x FNE	-0.000	0.001	-0.002	t(98)=-.25	0.801
FNE x n-back	0.001	0.001	0.004	t(98)=.82	0.413
Condition x n-back x FNE					
Presence vs. Anonymous x n-back x FNE	0.000	0.001	0.001	t(97)=.20	0.839
Threat vs. Presence & Anonymous x n-back x FNE	-0.001	0.001	-0.003	t(93)=-.72	0.472

Note. FNE=Fear of negative evaluation.

Table 6. Frontal theta, n-back level, and FNE predicting reaction times and accuracy in Study 2.

Predictor	***b***	***SE***	***β***	**Statistical test**	***p***
			Predicting reaction times (*b* path)		
Intercept	0.824	0.022		t(78)=36.93	**<.0001**
Frontal theta	0.020	0.003	0.072	t(27230)=7.15	**<.0001**
Frontal theta x n-back	0.008	0.005	0.012	t(1178)=1.75	0.081
Frontal theta x FNE	0.000	0.000	-0.001	t(27260)=.03	0.975
Frontal theta x n-back x FNE	0.001	0.001	0.006	t(1207)=.79	0.427
			Predicting accuracy (*b* path)		
Intercept	1.714	0.061		z=28.31	**<.0001**
Frontal theta	0.096	0.022	0.299	z=4.39	**<.0001**
Frontal theta x n-back	0.064	0.025	0.099	z=2.57	**0.010**
Frontal theta x FNE	-0.002	0.003	-0.057	z=-.84	0.400
Frontal theta x n-back x FNE	-0.009	0.003	-0.107	z=-2.80	**0.005**

Note. FNE=Fear of negative evaluation.

Table 7. Indirect effects of condition on accuracy through frontal theta at different levels of n-back and FNE in Study 2.

	Indirect effect *b*	***LLCI***	***ULCI***	***p***
2-back / low FNE	-0.0007	-0.0019	0.0003	0.14
2-back / moderate FNE	-0.0009	-0.0017	-0.0002	**0.01**
2-back / high FNE	-0.0012	-0.0023	-0.0002	**<.01**
3-back / low FNE	-0.0024	-0.0045	-0.0011	**<.01**
3-back / moderate FNE	-0.0022	-0.0034	-0.0012	**<.01**
3-back / high FNE	-0.0015	-0.0031	-0.0003	**0.02**

Note. FNE=Fear of negative evaluation; LLCI=lower limit of 95% confidence interval; ULCI=upper limit of 95% confidence interval.

Table 8. Condition and FNE predicting effort in Study 2.

Predictor	***b***	***SE***	**β**	**Statistical test**	***p***
			Predicting effort (*a* path)		
Intercept	4.099	0.090		t(99)=45.67	**<.0001**
Condition					
Presence vs. Anonymous	-0.015	0.041	-0.012	t(198)=-0.36	0.716
Threat vs. Presence & Anonymous	0.134	0.024	0.184	t(198)=5.67	**<.0001**
FNE	0.008	0.011	0.066	t(99)=.754	0.453
Condition x FNE					
Presence vs. Anonymous x FNE	-0.004	0.005	-0.026	t(198)=-.792	0.430
Threat vs. Presence & Anonymous x FNE	-0.003	0.003	-0.029	t(198)=-.894	0.373

Note. n-back level is not included because effort was only reported after each condition. FNE=Fear of negative evaluation.

Table 9. Effort, n-back level, and FNE predicting reaction times and accuracy in Study 2.

Predictor	***b***	***SE***	***β***	**Statistical test**	***p***
		Predicting reaction times (*b* path)			
Intercept	0.822	0.022		t(76)=37.39	**<.0001**
Effort	0.041	0.008	0.112	t(230)=5.24	**<.0001**
Effort x n-back	0.012	0.007	0.017	t(267)=1.88	0.062
Effort x FNE	-0.002	0.001	-0.043	t(216)=-1.93	0.054
Effort x n-back x FNE	-0.001	0.001	-0.006	t(245)=-.71	0.477
		Predicting accuracy (*b* path)			
Intercept	1.698	0.050		z=33.72	**<.0001**
Effort	0.175	0.031	0.470	z=5.62	**<.0001**
Effort x n-back	-0.116	0.026	-0.155	z=-4.38	**<.0001**
Effort x FNE	-0.007	0.004	-0.158	z=-1.89	0.058
Effort x n-back x FNE	-0.006	0.003	-0.067	z=-1.94	0.052

Note. FNE=Fear of negative evaluation.

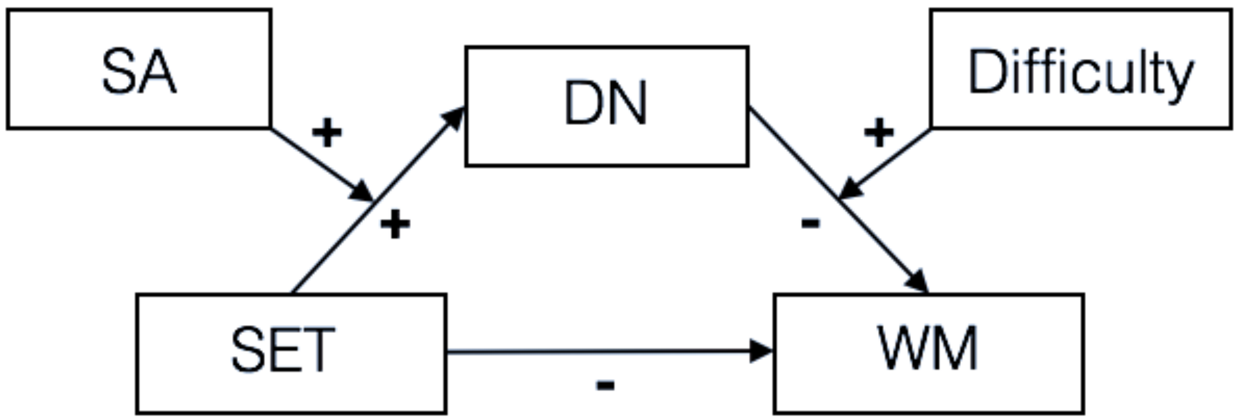

Figure 1. The predicted default network interference model of social-evaluative threat. SET=Social-evaluative threat; SA=Social anxiety; DN=Default network; WM=Working memory.

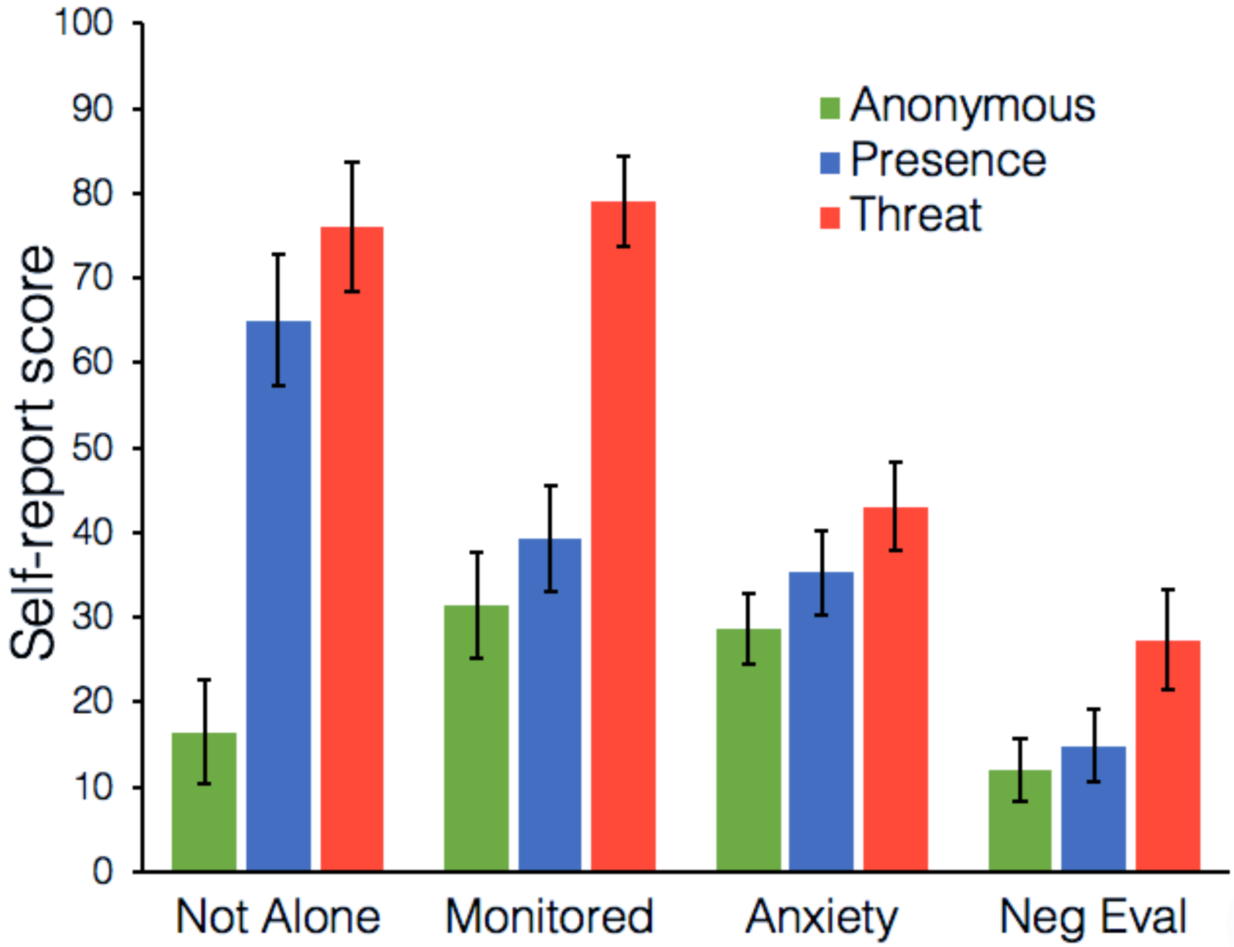

Figure 2. Means of state measures (feelings of not being alone, feelings of being monitored, feelings of anxiety, and feelings of being negatively evaluated) by social context condition in Study 1. Each measure was self-reported by the participant on a 0-100 scale following the condition. Error bars represent 95% confidence intervals.

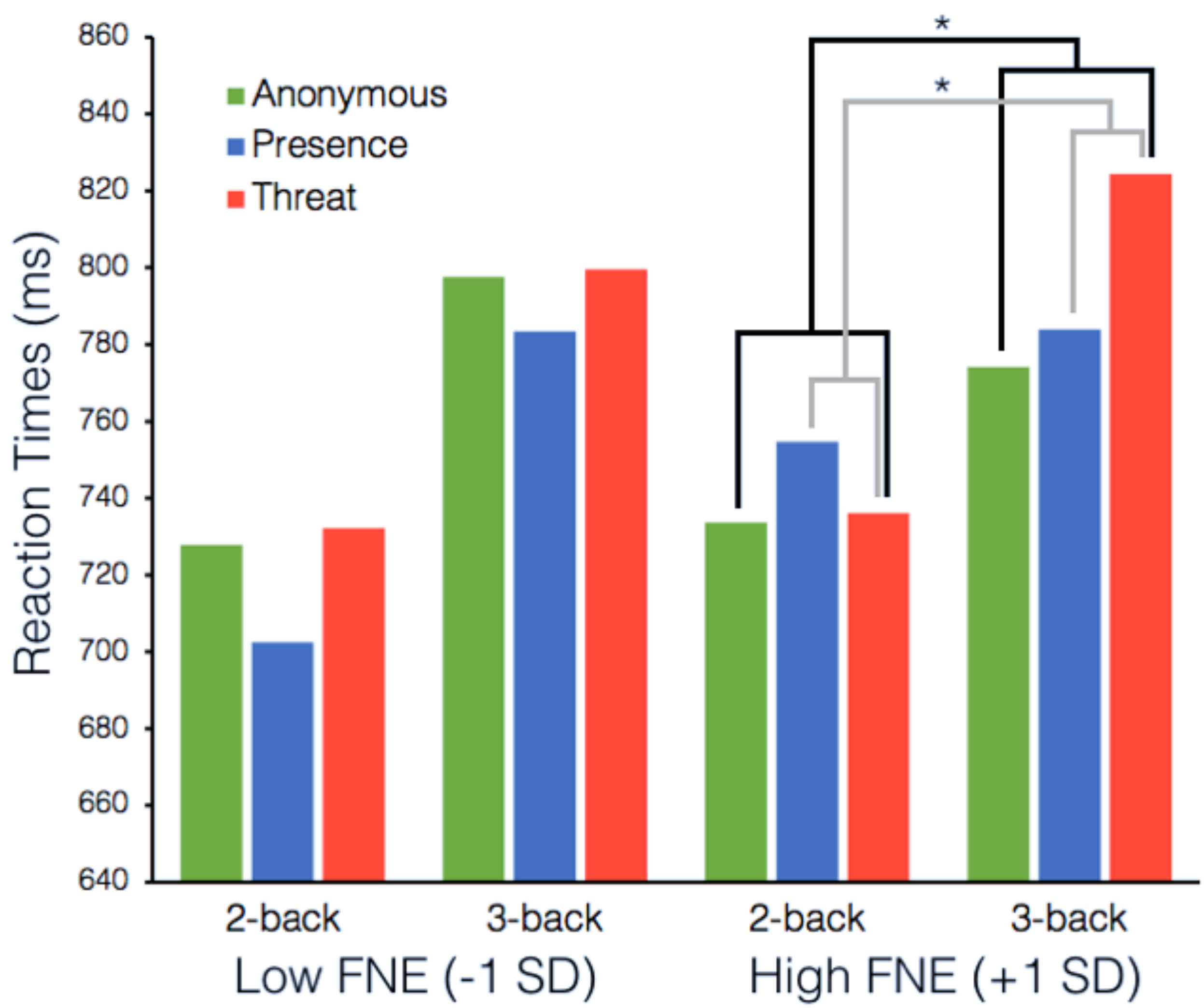

Figure 3. Three-way interaction between social context condition, n-back difficulty, and FNE predicting reaction times in Study 1. *$ps<.05$.

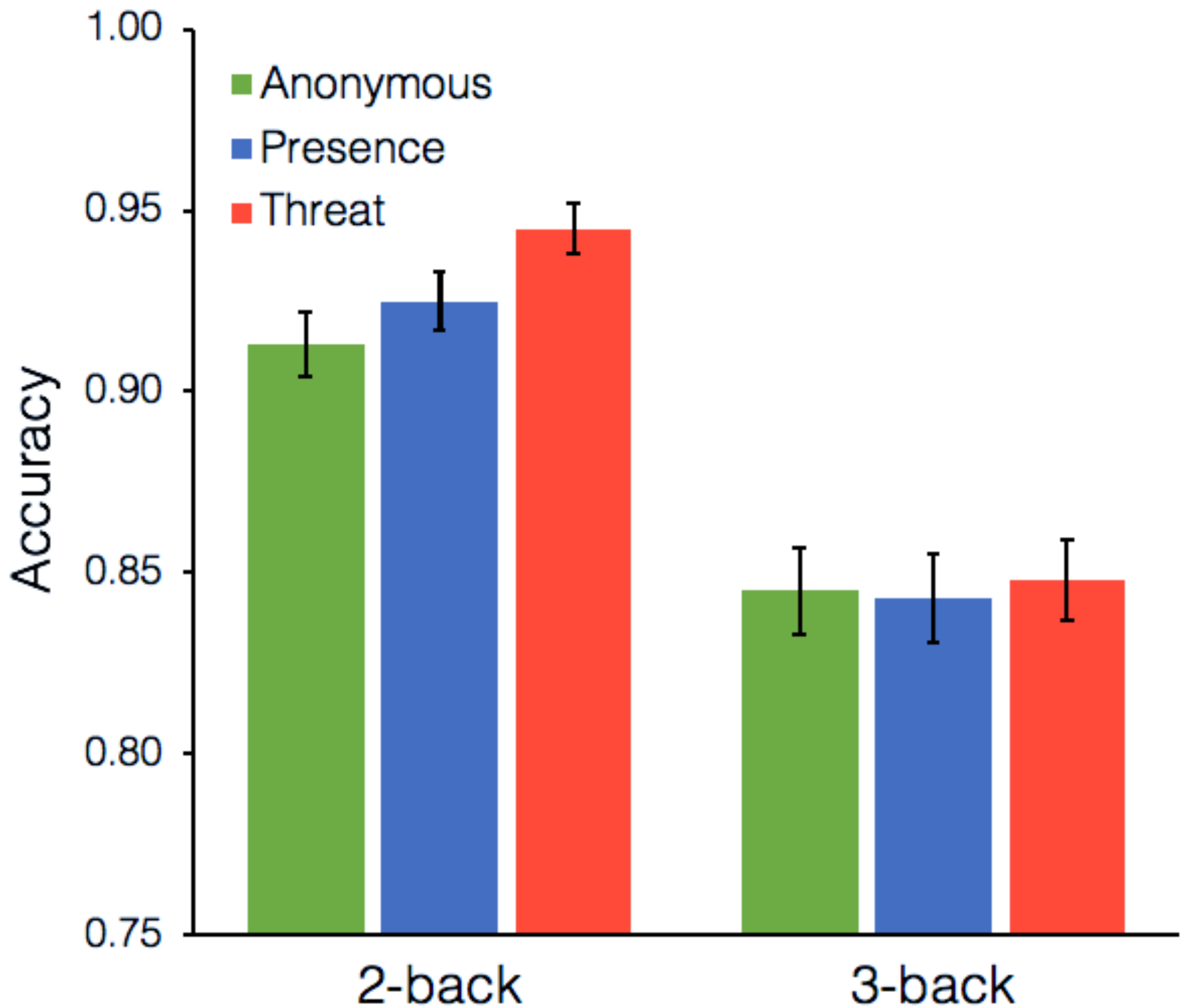

Figure 4. Two-way interaction between social context condition and n-back difficulty predicting accuracy in Study 1. Error bars represent 95% confidence intervals.

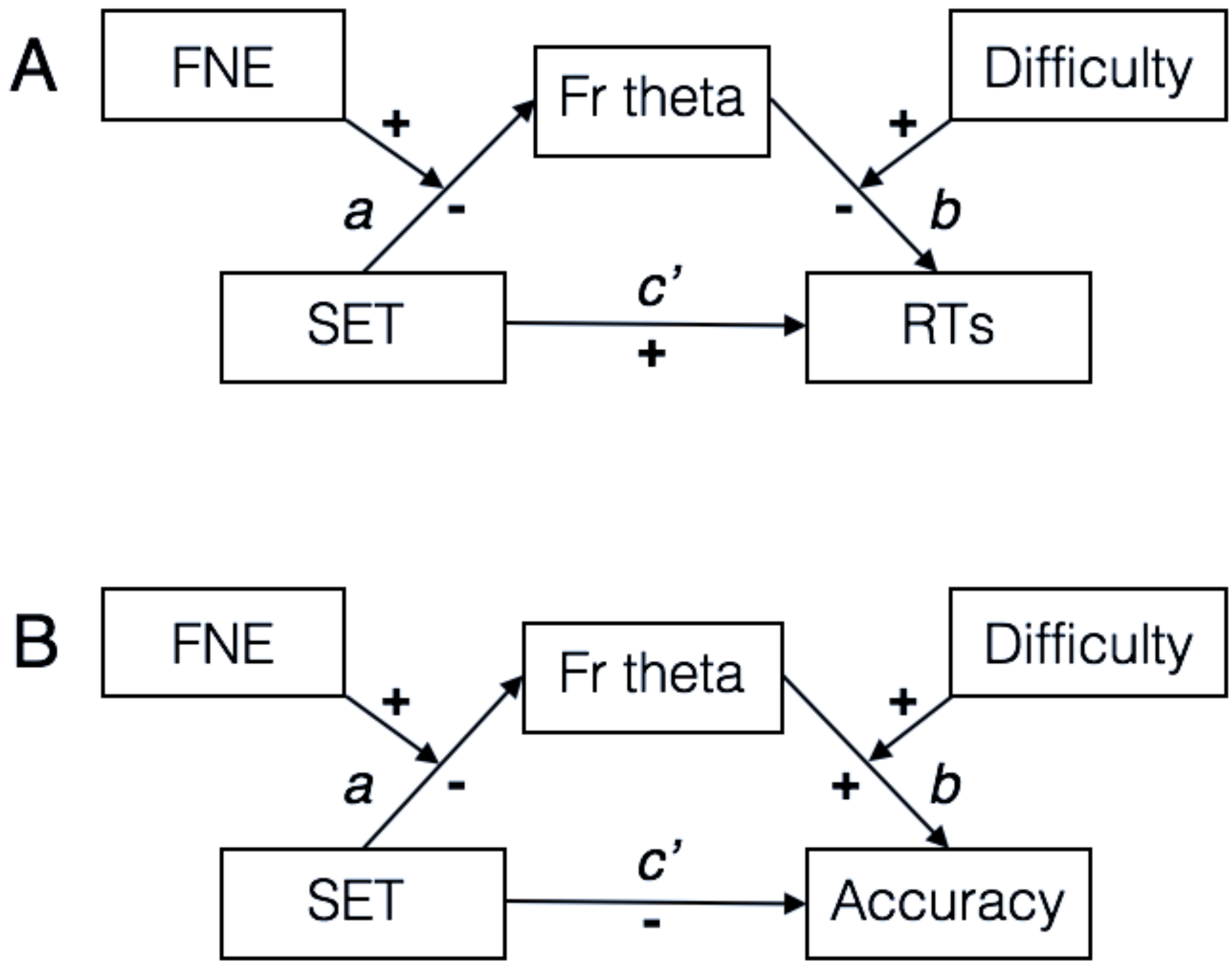

Figure 5. Hypothesized models for the default network interference hypothesis of SET predicting A) reaction times and B) accuracy. Frontal theta is thought to indicate *suppression* of default network activity. SET=Social-evaluative threat (Threat condition vs. Presence and Anonymous conditions); FNE=Fear of negative evaluation; Fr theta=Frontal theta; RTs=Reaction times.

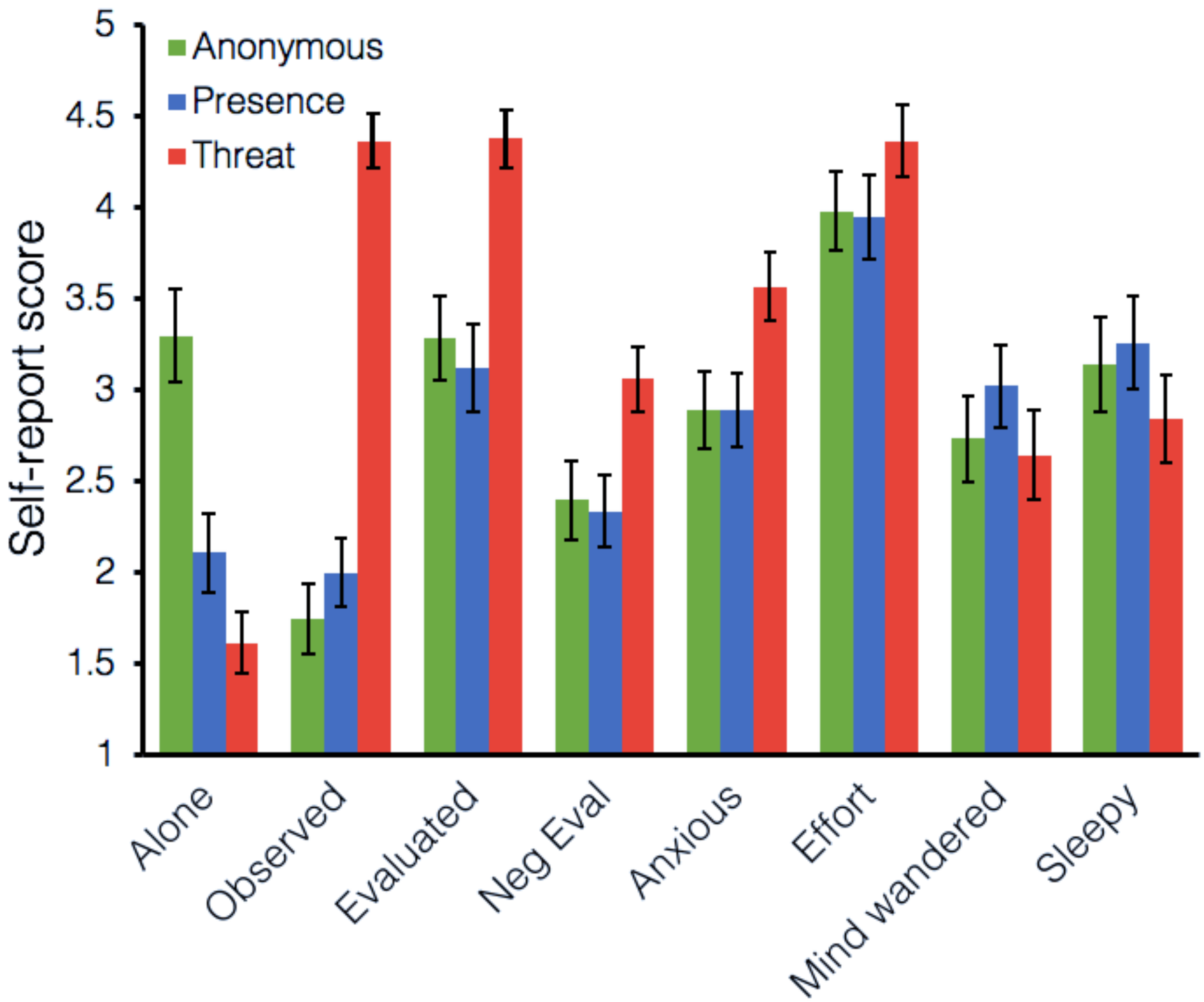

Figure 6. Means of state measures by social context condition in Study 2. Error bars represent 95% confidence intervals.

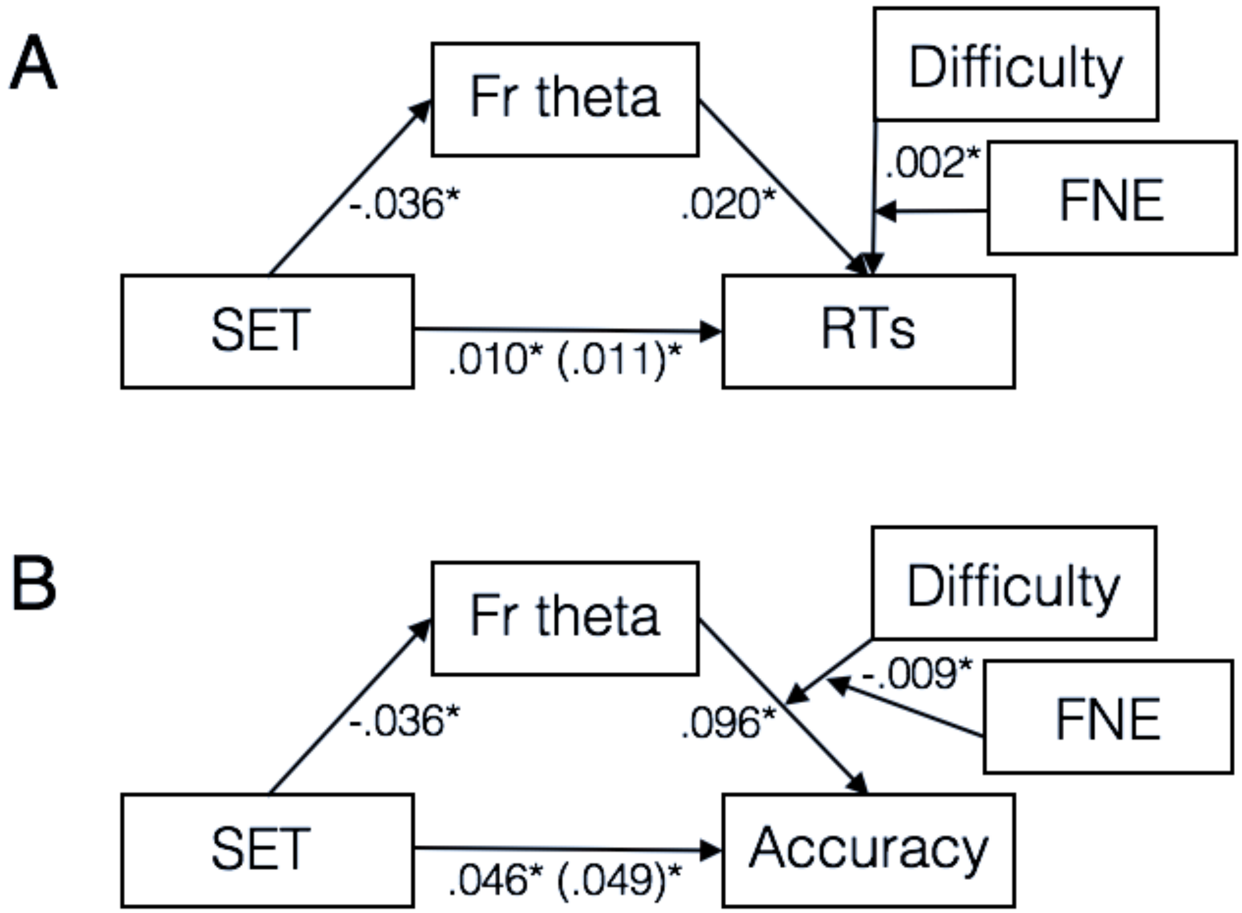

Figure 7. Moderated mediation of the effect of Threat vs. non-Threat (Presence and Anonymous) on performance (A. reaction times and B. accuracy) via an indirect effect of frontal theta in Study 2. Unstandardized betas; **p*s<.05. SET=Social-evaluative threat (Threat condition vs. Presence and Anonymous conditions); Fr theta=Frontal theta; FNE=Fear of negative evaluation; RTs=Reaction times.

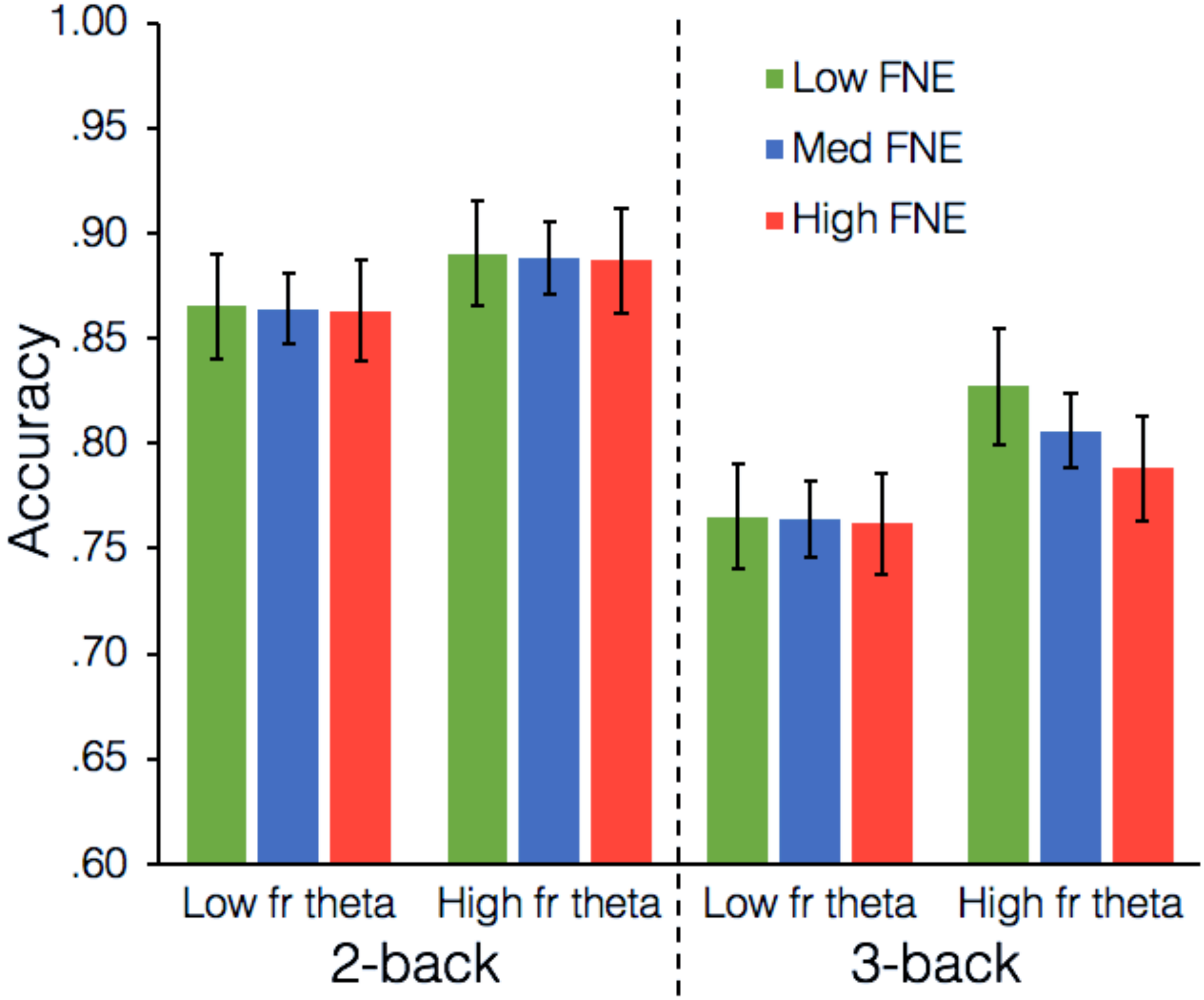

Figure 8. Three-way interaction between frontal theta, n-back difficulty, and FNE predicting accuracy in Study 2. Frontal theta and FNE were analyzed as continuous variables but are displayed here as categorical variables for visualization purposes. Error bars represent 95% confidence intervals. FNE=Fear of negative evaluation; fr theta=frontal theta.

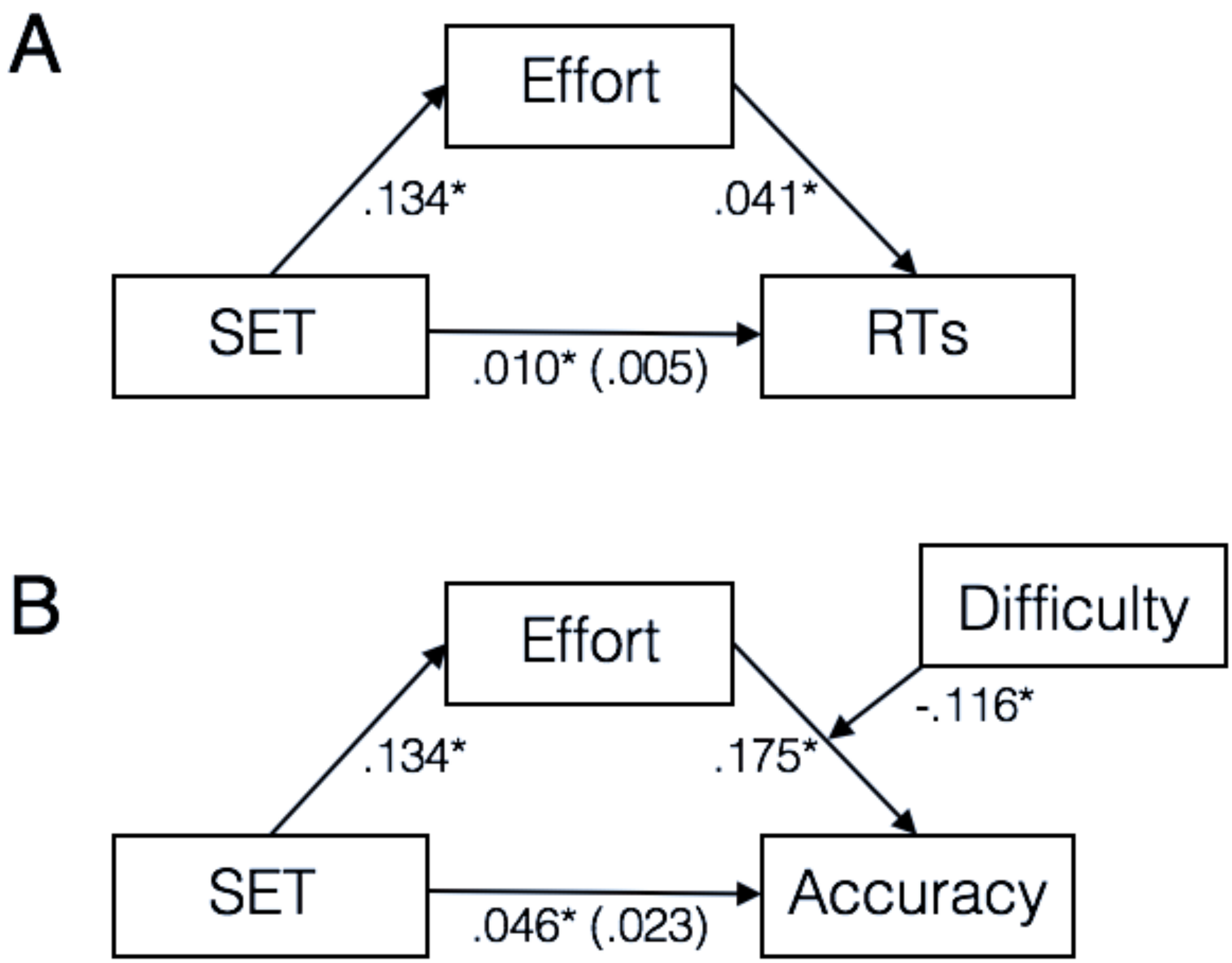

Figure 9. Moderated mediation of the effect of Threat vs. non-Threat (Presence and Anonymous) on performance (A. reaction times and B. accuracy) via an indirect effect of effort in Study 2. Unstandardized betas, **p*s<.05. SET=Social-evaluative threat (Threat condition vs. Presence and Anonymous conditions); FNE=Fear of negative evaluation; RTs=Reaction times.