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Effect of attention control on sustained attention during induced-anxiety

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Abstract

Anxiety has wide reaching and complex effects on cognitive performance. Although it can intrude on cognition and interfere with performance, it can also facilitate information processing and behavioral responses. In a previous study, we showed that anxiety induced by threat of shock facilitates performance on the Sustained Attention to Response Task (SART), a vigilance test, which probes response inhibition to infrequent no-go stimuli. The present study sought to identify factors that may have contributed to such improved performance, including on- and off-task thinking (assessed with thought probes) and individual differences in attention control, as measured with the Attention Control Scale (Derryberry and Reed, 2002). Replicating our prior finding, we showed that shock threat significantly reduced errors of commission on the nogo trials. However, we extended this finding in demonstrating that this effect was driven by subjects with low attention control. We therefore confirm that anxiety increases inhibitory control of prepotent responses – a mechanism which is adaptive under threat – and show that this effect is greater in those who rely more upon such prepotent responding, i.e., those with low attentional control.

Keywords

anxiety; vigilance; stress; SART; threat of shock

Introduction

Anxiety is a state of distress, tension, and vigilance in response to threat. Anxiety is adaptive, it prepares organisms for action (Langner and Eickhoff, 2013), increases arousal, and facilitates bottom-up sensory processing (Cornwell *et al.*, 2007, Pessoa, 2009), but it can also disrupt top-down cognitive control caused by interference from internal and external

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task-irrelevant stimuli (Bar-Haim *et al.*, 2007, Eysenck *et al.*, 2007, Forster *et al.*, 2013). Research on the cognitive effects of anxiety has mostly focused on cognitive disruption by discrete external threats (e.g., attentional/affective bias) (Bar-Haim *et al.*, 2007), but little is known about the effect of anxiety on sustained attention tasks, when attention needs to be maintained over time (Forster *et al.*, 2013, Righi *et al.*, 2009). On the one hand, vigilance tasks would seem to be especially vulnerable to lapses of attention, including disruption by anxious cognition (Forster *et al.*, 2013, Horowitz and Becker, 1971, Smallwood *et al.*, 2009, Su *et al.*, 2009, Vinski and Watter, 2013). On the other hand, vigilance tasks could benefit from the arousing and and energizing properties of anxiety (Easterbrook, 1959, Lang *et al.*, 1992, Langner and Eickhoff, 2013).

In a previous study, we reported that anxiety induced by threat of shock improved performance on a vigilance task, the Sustained Attention to Response Task (SART) (Robinson *et al.*, 2013a). The present study sought to extend these findings by examining the potential role that attentional lapses and individual differences in attention control may play in such anxiety-related improved performance.

During SART, subjects respond to high-frequency go trials and inhibit responses to rare nogo trials. Because of the tedious nature of SART, subjects progressively withdraw their attention, which promotes attentional lapses and 'mind wandering' (also called task-unrelated thoughts, TUTs) (Robertson *et al.*, 1997, Smallwood *et al.*, 2004), leading to nogo commission errors (i.e., failure to inhibit response to nogo trials) (McVay and Kane, 2012b, Robertson *et al.*, 1997). Studies have found inconsistent effects of anxiety on SART so far. While we reported that anxiety induced by shock threat improved nogo accuracy (i.e., improved inhibition of the prepotent go response) (Robinson *et al.*, 2013a), a finding we are replicating in several ongoing studies, including a study in patients with anxiety disorders, a recent study showed an association between trait anxiety and slower go RT in periods without nogo errors (Forster *et al.*, 2013). This latter finding is consistent with cognitive theories of anxiety, according to which anxiety-induced performance deficits are caused by worry and self-preoccupation, which take up limited processing resources necessary to perform the task (Eysenck *et al.*, 2007) or by poor attention control (Bishop, 2009). However, another study reported no effect of state or trait anxiety on reaction time (RT) or accuracy during SART (Righi *et al.*, 2009). A key difference between our study and these studies is that we examined the effect of changes in state anxiety via an experimental threat manipulation, whereas the two other studies examined individual differences in trait anxiety. Hence, in the absence of an experimental manipulation to increase state anxiety, state anxiety may have been too low to detect an effect in (Righi *et al.*, 2009), and the performance impairment associated with trait anxiety may reflect individual differences of personality characteristics in (Forster *et al.*, 2013). Furthermore, while high trait anxiety may be associated with poor attention control (Forster *et al.*, 2013), an increase in state anxiety may, depending of the task, be associated with better attention control (Robinson *et al.*, 2013b), as suggested by our previous findings (Robinson *et al.*, 2013a). In fact, the ability to increase response inhibition during an anxious state may be adaptive (Birk *et al.*, 2011). It is also consistent with theoretical models linking anxiety to activation of the behavioral inhibition system (Gray, 1987, Quay, 1997, Wright *et al.*, 2014).

In our initial study, we expected that anxiety induced by shock threat would impair performance (Robinson *et al.*, 2013a). This was based on two assumptions. First, because SART promotes TUTs (Robertson *et al.*, 1997) and TUTs are increased by personal concerns, worries, stress, and negative mood (Horowitz and Becker, 1971, Klinger, 1971, McVay and Kane, 2010, Su *et al.*, 2009), we assumed that threat would promote anxious mentation and increase overall TUTs. Second, this increase in anxious TUTs would take up limited resources dedicated to the task, hence impairing performance (Eysenck *et al.*, 2007). The fact that shock anticipation did not impair SART performance suggests that shock threat did not increase TUTs. In other words, TUTS may not have affected the influence of state anxiety on performance. One objective of this study was therefore to probe subjects' thoughts while performing the task to examine the effect of shock threat on TUTs. Using real-time probe sampling (Gruberger *et al.*, 2011, Teasdale *et al.*, 1995), we assessed three types of thoughts, task-relevant thoughts (TRTs) and two types of TUTs, threat-related TUTs (threatTUTs) and non threat-related TUTs (nonthreatTUTs) (see Methods). Based on our previous findings that performance was not impaired by induced anxiety (Robinson *et al.*, 2013a), contrary to some theories (McVay and Kane, 2010), we did not expect that TUTs would be affected by shock anticipation. Rather, we expected increased threatTUTs (and decreased nonthreatTUTs) during shock anticipation compared to safe periods.

One mechanism by which shock threat could improve SART performance is via increased arousal or motivation (Chiles, 1958, Spence *et al.*, 1956), which could then enhance the ability to cope with vigilance tasks (Singh *et al.*, 1979), or via activation of the behavioral inhibition system (Gray, 1987, Quay, 1997, Wright *et al.*, 2014). Poor performance during SART is more likely to be found in individuals with a weakened ability to inhibit prepotent responses or to cope with the monotonous nature of the task, resulting in impaired goal maintenance or sustained attention (Helton *et al.*, 2009, McVay and Kane, 2012a, Robertson *et al.*, 1997). Such characteristics are linked to attention control, the executive ability to direct attention (Judah *et al.*, 2013). Accordingly, individuals most likely to benefit from shock threat are those with a weakened ability to cope with the monotonous nature of vigilance tasks, i.e., individuals with poor attention control (McVay and Kane, 2012a, Robertson *et al.*, 1997). One possibility, therefore, is that individuals with low attention control are those who contribute to the improved performance during shock threat. Indeed, because they should show poor SART performance under safe condition, they should be more likely to benefit from threat-related increased arousal or motivation or activation of the behavioral inhibition system. By contrast, individuals with high attention control are unlikely to benefit from shock threat because they should show high and stable performance independently of the testing context. This hypothesis is consistent with results of a recent study that showed that shock threat improved cognitive performance during a continuous performance task and a working memory task only in subjects with low attention control (Hansen *et al.*, 2009). Based on these findings, we expected lower attention control subjects to show lower performance in the absence of threat but that their performance would improve during shock threat. Attention control was measured using the Attentional Control Scale (ACS) (Derryberry and Reed, 2002, Rothbart and Derryberry, 1981), a well-established questionnaire that assesses self-regulatory control associated with goal maintenance, attention shifting, effortful attention, and resistance to prepotent responses

(Derryberry and Rothbart, 1997, Evans and Rothbart, 2007), such as nogo responses (Herrmann *et al.*, 2003, Wiersema and Roeyers, 2009).

To summarize, this study examined the impact of shock threat on TUTs and assessed whether individual differences in attention control contributed to the influence of state anxiety on SART performance. Analyses focused on nogo commission errors (i.e., failure to inhibit prepotent responses), as omission errors to go trials were minimally affected by shock threat in our previous study (Robinson *et al.*, 2013a).

Material and Method

Participants

Sixty healthy volunteers (31 female) completed the study. Subjects were included based on: (1) no past or current psychiatric disorders according to SCID-I/P (First *et al.*, 1995), (2) no medical condition that interfered with the objectives of the study as established by a physician, and (3) no use of illicit drugs or psychoactive medications according to history and confirmed by a negative urine screen. All subjects gave written informed consent approved by the National Institute of Mental Health (NIMH) Human Investigation Review Board and were compensated for their participation.

Procedure

We used a similar procedure as in our prior study (Robinson *et al.*, 2013a), except that thought probes were added to the task. Briefly, subjects performed SART during alternating safe conditions, when they were safe from shock, and threat conditions, when they were at risk of receiving unpredictable (and performance-independent) unpleasant shocks. Subjects' anxiety level was assessed with subjective reports and the acoustic startle reflex (i.e., the ocular motor response to a loud burst of noise). This reflex was utilized because it is robustly increased by aversive states and constitutes a reliable measure of anxiety (Grillon, 2008). One of the advantages of the startle methodology is that, because it is a response to an external stimulus under control of the experimenter, it can be used to probe ongoing changes in anxiety state.

Following attachment of the electrodes, nine startle stimuli were delivered every 18–25 s during the habituation phase. This was followed by a shock work-up procedure that sets the shock intensity at a level that was uncomfortable but not painful (a 4 on a scale of 1 to 5, where 1 is barely perceptible and 5 is painful) by gradually increasing the intensity of the shock. Next, subjects performed a variant of SART (Robertson *et al.*, 1997) in alternating safe and shock threat conditions.

Sustained Attention to Response Task (SART)

The stimuli were presented on a monitor. Participants were asked to respond to frequent "go" stimuli ("=") and to withhold their response to occasional "nogo" stimuli ("O"). These stimuli were randomly distributed and were presented for 250 ms at a rate of one every 2000 ms. There were two runs with a 5-min rest between runs. Each run consisted of a total of six continuous 110-s SART blocks: three safe blocks alternating with three threat blocks. In each block, the go stimuli were presented on 50 occasions while the no-go stimulus occurred five times per block for a total of 150 go and 15 no-go trials (adding up to 10% of total trials) per safe or threat condition. The first SART block was counterbalanced between runs and across subjects such that half of the subjects started with a safe and a threat condition in the first and second runs, respectively, and the other half with the reverse order. Subjects were asked to focus equally on speed and accuracy.

Startle stimuli, shocks, and threat condition

In each run, SART started with three startle stimuli (before the first go/nogo block). Subsequently, three startle stimuli were delivered in each block to assess subjects' anxiety. Startle stimuli always occurred between two go trials. A single shock was delivered at the end of one of the threat block in each run just prior to a go trial that was not included in the analysis (for a total of two shocks during the experiment). Subjects were informed that shock could be administered only in the threat condition and never in the safe condition. They were told that the computer decided the number of shocks and time of shock delivery, and that the probability of shocks did not dependent on their performance. The onset of the safe and threat conditions were signaled by a text on the monitor that indicated “you are safe from shock” and “you are at-risk of shock”, respectively. After each run, subjects rated retrospectively their anxiety in the safe and threat condition on an analog scale ranging from 0 (not at all anxious) to 10 (extremely anxious).

Thought probes

Immediately after each startle stimulus in the go/nogo blocks, questions on the monitor prompted subjects to report their thoughts on a response key pad with choices of: task-related thoughts (TRT), threat-related (anxious) task-unrelated thoughts (threatTUTs), or threat-unrelated (non-anxious) task-unrelated thoughts (nonthreatTUTs). Thus, subjects were asked to report their thoughts 18 times in the safe conditions (3 thought probes x 3 blocks x 2 runs) and 18 times in the threat condition. Subjects were given the following instructions:

> “Occasionally during the task you will be asked to rate whether your thought was task-related, task-unrelated but threat-related, or task-unrelated and threat-unrelated. If you were thinking about the task, then we'll say you were having a task-related thought. If you were thinking about the threat, then we'll say you were having a threat-related thought. If you were not thinking about the task and not thinking about the threat, then you were having a task-unrelated and threat-unrelated thought. The question you need to answer after each loud noise is, “Was I thinking about doing the task,” “Was I thinking about the threat,” or “Was I thinking about something other than the task or the threat?” Let's define what I mean by “task-related thoughts,” “threat-related thoughts,” and “task-unrelated and threat-unrelated thoughts.”
>
> A task-related thought is thinking about performing the task, paying attention to the stimuli and your responses.

> A threat-related thought is any thought that is focused solely on the threat experiment. For example, you may be thinking about how uncomfortable is the shock, when it will be administered, how you feel, or when the current condition will stop.
>
> A task-unrelated and threat-unrelated thought is not thinking about the task or the threat of shock. For example, you may think of something you did this morning or last night, a friend, teacher, or family member, or what you will do later during the day. Your mind may wander and you may have thoughts and images about things that have nothing to do with the threat, such as whether you are hungry or tired, etc."

Questionnaires

During the screening procedure, which occurred 1–3 weeks prior to testing, subjects were asked to fill out: Spielberger trait anxiety inventory (Spielberger, 1983) and the Attentional Control Scale (Derryberry and Reed, 2002). The ACS is a 20-item self-report scale that measures attentional focusing (9 items) and attentional shifting (11 items) (Derryberry and Rothbart, 1997). Higher scores on ACS reflect better ability to direct and maintain attention.

Stimulation and Physiological Responses

Stimulation and recording were controlled by a commercial system (Contact Precision Instruments, UK). The acoustic startle stimulus was a 40 ms duration 103-dB (A) burst of white noise presented via headphones. The eye blink reflex was recorded with two electrodes placed under the left eye and a ground electrode placed on the left arm. The electromyographic (EMG) eyeblink signal was amplified with bandwidth set to 30–500 Hz and digitized at a rate of 1000 Hz. The shock was administered either on the left wrist or on the left middle and ring fingers, depending on where the subject reached the desired intensity.

Data Analysis

For the go trials, correct responses consisted of any go trial in which there was a response, and for the nogo trials, correct trials were those in which no response was provided. Performance was determined for each condition (threat, safe) and trial type (go, nogo) by dividing the number of correct trials by the total number of each trial type. The one trial following a shock was excluded from analyses. Three measures of RT were also computed because they inform on the nature of information processing during SART. These included mean correct-go RT, to assess speed/accuracy trade-off (Peebles and Bothell, 2004), go RT variability, a measure of endogenous attention (Hu *et al.*, 2012, McVay and Kane, 2009), and pre-nogo RT. This latter measure provides an assessment of the development of habitual responses and attentional lapses because nogo errors of commission are usually preceded by faster RT (Robertson *et al.*, 1997). Response variability was determined by calculating the standard deviation of the mean RT for go trials for each subject. Pre-error RTs were averaged across the four go trials before nogo trials, averaged separately for each condition, and stratified into correct and error of commission nogo trials (Robertson *et al.*, 1997).

After full-wave rectification and smoothing the EMG signal, peak startle/eye blink magnitude was determined in the 20–100-ms timeframe following stimulus onset relative to a 50-ms pre-stimulus baseline. The startle responses from each participant were transformed to z scores and converted to T scores and then averaged separately within the safe and the threat conditions. The subjective anxiety scores were also averaged within each condition.

Because the thoughts (TRTs, threatTUTs, nonthreatTUTs) scores were not normally distributed, they were normalized with a square root transformation. They were analyzed in two steps. First, we examined whether the rate of TRTs changed between conditions. Second, we assessed the change in the rates of TUTs (threatTUTs vs. nonthreatTUTs) between conditions. Data were analyzed with mixed-model repeated measures analyses of variance (ANOVAs) and t-tests. Multiple regression analyses were used to identify unique predictors of nogo accuracy. Partial correlations (r_s) are also reported.

Results

Demographic

Subjects' mean (sem) trait anxiety and ACS scores were 28.0 (.8) and 59.9 (.9), respectively. Trait anxiety and ACS scores were negatively correlated (r=−.33, p<.01).

Anxiety measures

As expected, startle magnitude was larger in the threat (mean = 52.0, sem = .28) compared to the safe (mean = 46.4, sem = .28) condition (t(59)=8.7, p<0001), and retrospective ratings of anxiety were also higher in the threat (mean = 2.6, sem = .2) compared to the safe (mean = 5.2, sem = .3) condition (t(59)=12.1, p<0001).

Performance

Nogo trial accuracy and go trial accuracy, mean RT, and RT variability were analyzed using paired t-tests between safe and threat conditions (Table 1). Replicating our previous finding (Robinson *et al.*, 2013a), accuracy to nogo trials (t(59)=3.6, p=0006) improved from the safe to the threat condition. This was paralleled by a decreased in RT variability to go trials from the threat to the safe condition (t(59)=2.5, p=01). There was also a trend for better accuracy to go trials (t(59)=1.7, p=08) in the threat compared to the safe condition with no significant change in RT to go trials between conditions (t(59)=1.3, ns).

Comparison of RT that preceded correct and incorrect nogo trials (Table 1) was conducted with a condition (safe, threat) x nogo trial type (correct rejection, error of commission) ANOVA. Two subjects had no nogo trials error and were not included in the analysis. The nogo trial type main effect was significant due to faster RT preceding errors compared to correct trials (F(1,57)=17.1, p=.0001). The condition effect was also significant due to faster response in the threat compared to the safe condition (F(1,57)=7.3, p=.009). There was no significant interaction effect.

Thought probes

Fig. 1 shows the frequency of each type of thought. The TRT and TUT (threatTUTs + nonthreatTUTs) scores were analyzed separately because of colinearity (TRTs + threatTUTs + nonthreatTUTs =1). Two main results emerged. First, the rates of TRTs did not significantly differ between the safe and threat conditions (t(59)=1.0, p=.32). Second, within the off-task thought categories (TUT), there was a differential effect of the safe/threat condition on thought types (condition x thought types: F(1,59)=49.6, p<.00009). There were more nonthreatTUTs than threatTUTs in the safe condition (t(59)=2.6, p=.009), and more threatTUTs than nonthreatTUTs in the threat condition (t(59)=5.1, p<.00009). Taken together, these results indicate that the rate of anxious thoughts (threatTUTs) increased in the threat compared to the safe condition, but this increase was at the expense of non-anxious mind wandering (nonthreatTUTs), not at the expense of TRTs.

To examine the validity of the thought probe methodology, we examined the association between thought types and our behavioral and physiological measures of performance and anxiety. We examined whether 1) TRTs correlated with an objective measure of endogenous attention, go RT variability (Hu *et al.*, 2012, McVay and Kane, 2009), and 2) threatTUTs correlated with measures of state anxiety (subjective anxiety and potentiated startle). The TRTs correlated negatively with RT variability only in the safe condition (r=−.25, p<.05), such that the more on-task the subjects reported to be, the less variable their RT was (or, conversely, the less on-task, the more RT variability). The threatTUTs correlated positively with subjective anxiety in the threat condition (r=.31, p<.03). In addition, the change in the rate of threatTUTs from safe to threat correlated positively with the difference startle magnitudes (i.e., fear-potentiated startle; r=.30, p=.03) and with the difference retrospective anxiety scores (r= .27, p=.04).

Correlation and regression

To investigate potential individual predictors of performance, correlations between nogo accuracy and ACS, trait anxiety, TRTs, go RT, and go RT-variability were first calculated separately for the safe and threat conditions to determine variables to be used in the multiple regression analysis. Nogo accuracy in the safe condition was positively correlated with ACS (r=.39, p<.01) and negatively correlated with go RT-variability (r=−.39, p<.01). Nogo accuracy in the threat condition was positively correlated with go mean RT (r=.32, p<.01) and negatively correlated with go RT-variability (r=.36, p<.01).

To test which of the variables that significantly correlated with nogo accuracy explained independent variance, separate stepwise multiple regression analyses were used with the nogo accuracy as the dependent variable for the safe and threat condition data. For the safe condition, the final model comprised three independent predictors, which together explained 44% of the variance; nogo accuracy was correlated positively with ACS (beta = .31, F = 9.1, p<.01; partial correlation r_s = .33, p<.01) and go mean RT (beta = .42, F =15.0, p<.001; r_s = 2.4, p=.06), and negatively with RT variability (beta = −.56, F =25.9, p<.0001; r_s =−.42, p<.001). For the threat condition, the final model included two independent predictors, which together explained 41% of the variance; nogo accuracy was correlated positively with the mean go RT (beta = .62, F =29.7, p<.0001; r_s=−.41, p<.001) and negatively with RT variability (beta = −.63, F =30.1, p<.0001; r_s=.33, p<.01). Thus, ACS did not contribute to the model in the threat condition.

The reason why ACS contributed to the model in safe but not threat was probably because only the low ACS subjects improved their performance from safe to threat (i.e., low ACS is associated with lower performance in safe but not in threat). To examine this possibility, an additional analysis examined potential predictors of the accuracy improvement from safe to threat. We conducted a stepwise regression analysis using the difference scores [threat minus safe] for nogo accuracy as the dependent variables. The potential predictors were ACS and the difference scores [threat minus safe] for the variables that correlated with performance in the safe or threat condition, i.e., threatTUTs, go RT mean, and go RT-variability. The final model explained 12% of the variance with only one variable, ACS, correlating *negatively* with the difference nogo accuracy score (beta = −.27, F =4.8, p<.03). Thus, the lower ACS was, the more go accuracy improved from safe to threat condition. For illustration purpose, we calculated nogo accuracy in the safe and threat conditions in low and high ACS groups based on a median split of ACS scores (Fig. 2). Accuracy in the high ACS group increased slightly and non-significantly from the safe to the threat condition (t(28)=.7, ns). In contrast, in the low ACS group, nogo accuracy improved significantly from the safe to the threat condition (t(30)=4.2, p=.0002).

Because a prior study reported slower RT in high trait anxious subjects, in a post-hoc analysis, we examined the association between trait anxiety and performance. Consistent with (Righi *et al.*, 2009), we found no significant correlation between trait anxiety and accuracy in the safe or threat conditions (all p>.2).

Discussion

In a prior study, we reported improved nogo accuracy during shock threat (Robinson *et al.*, 2013a). The present study replicates this finding, and, importantly, provides clues as to the variables that may have contributed to this performance improvement. Specifically, we identified individual differences in attention control as an important factor influencing performance distinctly during threat and safety. Other potential mechanisms will be discussed.

Individual differences in attention control emerged as a powerful modulator of performance on sustained attention during threat. Specifically, during the safe condition, low attention control, as assessed with ACS, was associated with lower performance (increased nogo errors of commission) compared to high attention control. This result is consistent with the role of attention control in sustained attention tests such as SART (Herrmann *et al.*, 2003, Wiersema and Roeyers, 2009). However, during shock threat, performance improvement was associated with low attention control, such that the threat condition permitted individuals with low attention control to perform at the level of individuals with high attentional control. Finally, in contrast to individuals with low attention control, those with high attention control performed similarly in the safe and threat conditions. It is unlikely that failure to improve during shock threat in this latter group was due to ceiling performance since responses were correctly inhibited on only 74% of the nogo trials. These findings are reminiscent of results of a shock threat study, in which low heart rate variability, indicating poor attention control (Healy, 2010, Nigg, 2006, Stifter and Jain, 1996, Thayer and Lane, 2000), was associated with improved cognitive performance during a threat relative to safe context (Hansen *et al.*, 2009). Thus, in Hansen et al' study and in our study, shock threat promoted an attentional state that benefited subjects with poor attention control, i.e., subjects who were most likely to be in a relative inattentive state. Conceivably, the impaired performance associated with low attention control in a safe environment could be due to reduced ability to cope with the tedious nature of the vigilance task, leading to poor effortful attention.

It is noteworthy that go RT-variability was reduced during threat condition, suggesting increased endogenous attention (Hu *et al.*, 2012, Manly *et al.*, 1999), an effect that may be related to increased prefrontal cortex activity (Forster *et al.*, 2013). Indeed, RT variability during cognitive tasks has been associated to prefrontal top-down control of attention (Bellgrove *et al.*, 2004, Johnson *et al.*, 2008). The threat condition might have raised arousal to an optimum attention control level, or it may have provided the motivation to increase attentional effort towards the task as a coping strategy to prevent distraction from threat processing and to reduce anxiety (Baumeister, 1991, Van Dillen and Koole, 2007). The increased performance (decreased nogo errors of commission) in the threat condition may have been an indirect benefit of this coping strategy.

These results, together with previous findings (Forster *et al.*, 2013, Righi *et al.*, 2009), suggest differential effects of trait anxiety and state anxiety on SART performance, with trait anxiety potentially impairing attention control, and state anxiety improving attention control. That trait anxious individuals perform poorly on SART is consistent with reports that such individuals exhibit poor attention control. In the present study, for example, trait anxiety correlated negatively with ACS. However, the post-hoc analysis showed that trait anxiety was not associated with poor performance. Because we did not attempt to recruit high trait anxious subjects, we do not know whether the present results would extend to high trait anxious individuals. In addition, it is possible that increased arousal due to shock threat compensated for poor attention control associated with high trait anxiety. However, in an ongoing study (data in preparation), we show no difference in SART performance between psychiatrically healthy controls and individuals with anxiety disorders (who, by definition, have high trait anxiety). Thus, in this regard, our results are consistent with Righi et al who reported no effect of trait anxiety on SART performance (Righi *et al.*, 2009). Finally, in our ongoing study, the anxious patients also show improved accuracy during shock threat. Hence, whether trait anxiety is associated with poor performance remain to be demonstrated. Of course, this does not mean that the underlying neural mechanisms supporting performance are similar in low and high trait individuals (Righi *et al.*, 2009). In fact, trait anxiety-related differences may be easier to identify at the neural level than at the level of behavior (Righi *et al.*, 2009).

Other potential mechanisms of improved performance (nogo accuracy) in the threat vs. safe condition can be proposed. SART performance is influenced by strategic speed-accuracy trade-off (Peebles and Bothell, 2004). Eysenck's Attention Control Theory stipulates that anxious individuals increase their efforts to keep performance to a level comparable to low trait anxious individuals (Eysenck *et al.*, 2007). This is reflected in slower RT to maintain accuracy (Eysenck *et al.*, 2007). In fact, a recent study reported that high trait anxious individuals slowed down their go-RTs during SART, probably to avoid making nogo commission errors ((Forster *et al.*, 2013) (but see (Righi *et al.*, 2009)). This RT slowdown was associated with reduced prefrontal cortex activation, suggesting poor prefrontal control (Forster *et al.*, 2013). The present study showed no effect of shock threat on go RT, indicating that the improved accuracy was not caused by a speed-accuracy trade-off.

Low attention control could also be associated with poor inhibitory control of prepotent responses, and shock threat might have helped to transiently improve inhibitory control. This latter hypothesis is consistent with studies showing a link between anxiety and enhanced motor inhibition to nogo trials (Righi *et al.*, 2009, Sehlmeyer *et al.*, 2010). It is also consistent with theoretical models that propose that anxiety activates the behavioral inhibition system (Gray, 1987, Quay, 1997, Wright *et al.*, 2014). At a neural level, both SART (Grahn and Manly, 2012, Pardo *et al.*, 1991) and anxious anticipation (Mechias *et al.*, 2010) activate the premotor cortex (Brodmann area 6), which is part of the Corbetta et al's dorsal attention network and is closely linked to the generation of action (Corbetta *et al.*, 2008). It is therefore possible that in the present study, response inhibition was facilitated by threat-related potentiation of this region's activity via input from the septo-hippocampal system, the region implicated in the behavioral inhibition system (Gray, 1987).

Because it has been argued that mind wandering depends on the extent to which the current context primes personally-relevant concerns (Klinger, 1971, McVay and Kane, 2010), one would expect that a monotonous task such as SART would be especially vulnerable to attentional lapses caused by self-referential mentation or anxious vigilance during shock threat. This assumption was not supported in the present study. Despite objective (startle) and subjective (retrospective rating) measures of heightened anxiety in the threat condition, shock threat did not increase the overall rate of TUTs; it increased anxious cognition (threatTUTs) at the expense of non-anxious cognition (nonthreatTUTs), but not at the expense of TRTs. One possibility is that there was a tendency for increased TUTs during the shock threat but that this tendency was neutralized by increased attention to the task, suggesting that subjects were prioritizing the task over the threat. Our previous results with a n-back task during shock threat suggests that only cognitively demanding tasks strongly inhibits or limits subjective and physiological responses to shock threat (Vytal *et al.*, 2012). Hence, one would expect that in a low demanding cognitive task, shock threat would lead to increases TUTs.

This study had strengths and limitations. Among the strengths, we manipulated anxiety in a within-subject design, and relied on well-established methods of fear induction and measurement (Grillon and Baas, 2003), and thought assessment (Gruberger *et al.*, 2011, Teasdale *et al.*, 1995). Regarding the latter method, the correlations between TRTs and RT variability, as well as threatTUTs and subjective anxiety and fear-potentiated startle provide some validity to our approach. Among the limitations, the probe methodology has its drawbacks. Probing for thoughts might interfere with the same process we attempted to study and might change the nature of the SART task by making it less tedious or by interfering with the task itself (Giambra, 1995). Yet, alternative to the probe thought methodology, such as retrospective questionnaires, have their distinct weaknesses (Ericsson and Simon, 1980). The introduction of thought probes did not seem to have disrupted our threat experiment since we replicated our previous finding (Robinson *et al.*, 2013a). To minimize interference from the probe thought methodology, we restricted the questions to a minimum. As a result, we did not assess thoughts that could have helped to interpret the data further. For example, we did not assess worries unrelated to the shock threat, that is, worries about performance (e.g., I am doing poorly) or unrelated to the experiment (e.g., I am going to the dentist tonight). However, two findings suggest that we successfully assessed anxious thoughts related to the shock threat: first, the threatTUTs were more frequent in the threat than the safe condition, and second the threatTUTs were correlated with subjective and objective (fear-potentiated startle) measures of anxiety. It is possible that worries about the experiment were included in TRTs (and worries unrelated to the experiment were classified as threatTUTs). This might have weakened our ability to find correlations between TRTs and performance.

To summarize, we replicated our previous finding that shock threat improve performance on SART. We showed that this effect applied essentially to subjects with low attention control. These subjects’ performance was impaired during nogo trials in the safe condition (compared to the high attention control subjects), but nogo performance was restored in the threat condition, perhaps as a result of non-specific increased in cortical arousal and/or improved inhibitory control of prepotent responses. We also found that, while the levels of threat-related TUTs increased in the threat condition, they did so at the expense of non threat-related TUTs, not TRTs. This may partly explain the reason why worrisome thoughts did not interfere with performance.

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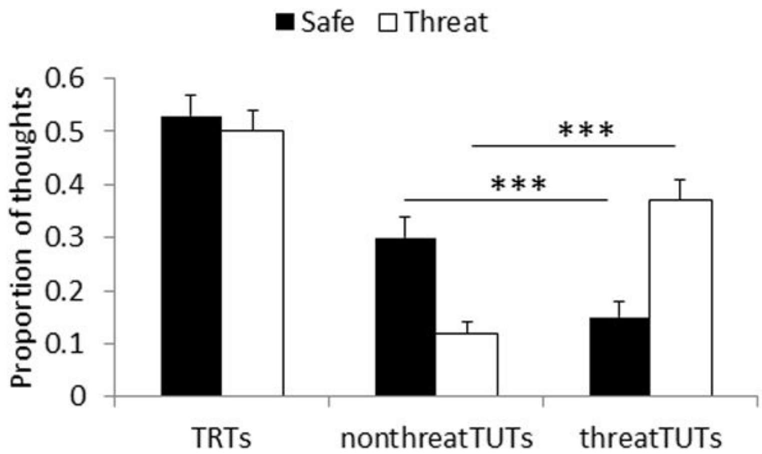

Fig. 1.

Proportion of each thought type in the safe and threat conditions. TRTs = task-related thoughts; nonthreatTUTs = threat-unrelated and task-unrelated thoughts; threatTUTs = threat-related and task-unrelated thoughts. Error bars are standard error of the mean. *** for p<.0009.

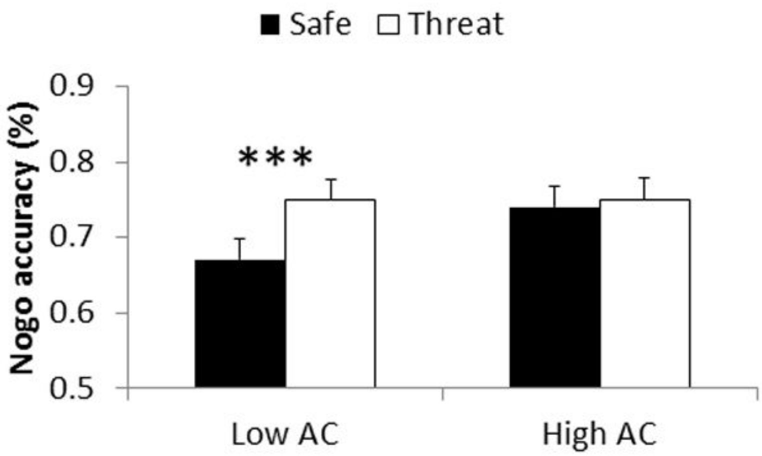

Fig. 2.
Accuracy rates on nogo trials during the safe and threat conditions in the low and high ACS groups. Error bars are standard error of the mean. *** for p<.0009.

Table 1

Performance to go and nogo trials in the safe and threat condition

	Safe	Threat
Nogo accuracy	.70 (.02)	.75 (.02)**
Go accuracy	.89 (.01)	.90 (0.1)
Go RT	342.3 (6.1) ms	339.2 (6.1) ms
Go variability	133.0 (8.0) ms	120.1 (8.0) ms*
RT to 4 go trials before nogo trials		
- **Correct omission**	341.5 (8.0) ms	338.2 (7.3) ms
- **Commission errors**	324.1 (10.6) ms^	298.5 (7.7) ms^

*for p=.015;

**for p=.0006;

^for main effect of false alarm vs. correct omission: p=.0001