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Inhibitory attentional control under cognitive load in social anxiety: An investigation using a novel dual-task paradigm.

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ABSTRACT

Research suggests that socially anxious (SA) individuals exhibit poorer attentional inhibition than their non-anxious (NA) counterparts. Attentional control theory presumes that cognitive load worsens the adverse effects of anxiety on attentional inhibition. However, previous studies examined the effects of cognitive load on attentional inhibition in social anxiety yielded inconsistent results. In this study, cognitive load was manipulated by adding a *1*-back (low cognitive load) and *2*-back task (high cognitive load) to the emotional antisaccade task, investigating the effects of cognitive load on attentional inhibition in the presence of social evaluative stimuli in SA and NA individuals. Results revealed that cognitive load improved the efficiency but impeded the effectiveness of inhibitory attentional control in SA participants. Under high cognitive load, SA participants made more erroneous saccades for threat-related than nonthreat-related faces while NA participants showed no differences in error rates among different face types. Moreover, regardless of cognitive levels, SA participants had shorter saccade latencies for angry faces than happy and neutral faces. NA participants did not show differences in saccade latencies among different face types. Implications of these findings for understanding the role that cognitive load plays in the processes of attentional control and interventions for social anxiety are discussed.

1. Introduction

According to cognitive theories, attentional biases toward threat-related information constitute a cognitive vulnerability factor that contributes to the development and maintenance of anxiety disorders, including social anxiety disorder (SAD) (Beck & Clark, 1997; Heimberg, Brozovich, & Rapee, 2014; Mogg & Bradley, 1998; Pergamin-Hight, Naim, Bakermans-Kranenburg, van, & Bar-Haim, 2015; Rapee & Heimberg, 1997). Several past studies using either reaction time-based tasks (Bantin, Stevens, Gerlach, & Hermann, 2016; Van Bockstaele et al., 2014) or eye-tracking paradigms (Armstrong & Olatunji, 2012; Garner, Mogg, & Bradley, 2006) have shown that socially anxious (SA) individuals demonstrate facilitated attentional engagement toward (Klumpp & Amir, 2009; Pishyar, Harris, & Menzies, 2004; Vassilopoulos, 2005) and difficulty in disengagement from socially threatening stimuli (Amir, Elias, Klumpp, & Przeworski, 2003; Buckner, Maner, & Schmidt, 2010; Liang, Tsai, & Hsu, 2017; Schofield, Johnson, Inhoff, & Coles, 2012). Additionally, the causal relation between attentional bias and social anxiety is supported by the findings of several studies in which reductions in attentional bias toward threat alleviated social anxiety (Amir et al., 2009, 2010; Heeren, Mogoase, Philippot, & McNally, 2015; Liang & Hsu, 2016).

In recent times, the critical role of attentional control in the underlying cognitive mechanisms of anxiety-related attentional biases has been highlighted by several models (Eysenck, Derakshan, Santos, & Calvo, 2007; Heeren, De Raedt, Koster, & Philippot, 2013; Mogg & Bradley, 2018). Attentional control refers to the ability to voluntarily and flexibly control and regulate attention allocation to facilitate the achievement of a current goal (Derryberry & Reed, 2002). Attentional control supports multiple functions, including inhibition (ignoring goal-irrelevant stimuli), shifting (switching attention between different goals), and working memory updating (removing goal-irrelevant stimuli from working memory) (Eysenck et al., 2007; Miyake et al., 2000; Miyake & Friedman, 2012). Among these functions, inhibition (also known as inhibitory attentional control or goal-directed inhibitory control) is considered the core component of attentional control that is executed by the top-down goal-directed attentional system (Mogg & Bradley, 2018). Whether anxious individuals demonstrate threat-related attentional biases depends on the interaction between top-down goal-directed and bottom-up salience-driven attentional systems (Petersen & Posner, 2012; Posner & Petersen, 1990). The former system is responsible for implementing goal-directed tasks, whereas the latter system is

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responsible for rapidly detecting and responding to motivationally salient stimuli (Corbetta & Shulman, 2002). An imbalance between these two systems results in attentional biases (Heeren et al., 2013; Mogg, Waters, & Bradley, 2017).

The bottom-up salience-driven attentional system plays a crucial role in the automatic evaluation of the motivational salience of input stimuli (Mogg & Bradley, 2016). Stimuli perceived to have highly aversive emotional salience (e.g., socially threatening stimuli) is assigned an initial processing priority. This would automatically trigger attentional orienting to these threatening stimuli (Cooper & Langton, 2006; Corbetta & Shulman, 2002; Mogg & Bradley, 1998; Mogg, Bradley, De Bono, & Painter, 1997). Consequently, such a prioritized orienting to threats will disrupt current goal-directed tasks by allocating attention to goal-irrelevant (i.e., threatening) rather than goal-relevant stimuli (S. Chen, Yao, Qian, & Lin, 2016; Eysenck et al., 2007). For example, during social situations, SA individuals tend to overestimate the aversive salience of cues that connote evaluations from others (e.g., facial expressions) and prioritize the processing of these potentially or mildly threatening stimuli. This attentional bias toward potential and mild threat cues interferes with their performance on goal-directed tasks (i.e., social interactions or social performance) (Heimberg et al., 2014).

However, the top-down goal-directed system can modulate the activity of the bottom-up salience-driven system that triggers attentional biases toward threat cues (Mohanty & Sussman, 2013; Vromen, Lipp, Remington, & Becker, 2016). Goal-directed inhibitory control supports the maintenance of a goal-directed task by suppressing interference from goal-irrelevant information and resolving conflicts between goal-relevant and -irrelevant stimuli (Mogg & Bradley, 2018). Neuroimaging studies have found that the neural networks involved in attentional control (e.g., prefrontal cortex) can downregulate amygdala activity. This suggests that the top-down goal-directed system contributes to emotion regulation by decreasing the responses of the bottom-up salience-driven system to threatening stimuli (Andrewes & Jenkins, 2019; Banks, Eddy, Angstadt, Nathan, & Phan, 2007). Accordingly, in SA individuals, attentional biases may result from: (a) an overactive bottom-up salience-driven system, which evaluates mild threats as having highly aversive salience; (b) an inefficient top-down goal-directed system, which leads to poor regulation of attentional allocation in the presence of socially threatening cues (Blair et al., 2012; Heitmann et al., 2017).

Using the antisaccade task, previous studies have found that anxious individuals demonstrate impaired attentional control compared to non-anxious (NA) individuals. Derakshan, Ansari, Hansard, Shoker, and Eysenck (2009) found that anxious individuals showed longer antisaccade latencies than NA individuals. This indicates that anxious individuals exhibit less efficient attentional inhibition than their NA counterparts. Similar impairments in attentional inhibition efficiency have been observed among SA individuals (Liang, 2018). These findings are consistent with the attentional control theory (ACT), which posits that anxiety impairs attentional control and has a greater impact on processing efficiency (indicated by response latency) than on performance effectiveness (indicated by accuracy) (Eysenck et al., 2007). However, a study conducted by Wieser, Pauli, and Mühlberger (2009) revealed that SA individuals demonstrated impaired performance effectiveness when they were exposed to socially threat-related stimuli (i.e., facial expressions). Specifically, SA individuals committed more erroneous saccades than NA individuals when required to make antisaccades in response to emotional faces.

Moreover, ACT proposes that the adverse effects of anxiety on attentional control worsen as working memory task demands increase (Eysenck et al., 2007). Accordingly, increasing task difficulty or adding a secondary task to the primary task will increase working memory load and exacerbate the negative impacts of anxiety on attentional control, particularly the attentional inhibition of task-irrelevant distractors (Moriya & Tanno, 2010). However, previous studies investigating the effects of cognitive load on attentional control in anxious individuals yielded inconsistent results.

On the one hand, some past findings suggest that increased cognitive load leads to reduced inhibitory attentional control (Hester & Garavan, 2005; McKendrick, Butler, & Grealy, 2018) and greater difficulties in disengaging from threat-related distractors in individuals with high trait and social anxiety (Berggren, Koster, & Derakshan, 2012; Judah, Grant, Lechner, & Mills, 2013). Berggren, Richards, Taylor, and Derakshan (2013) also found that increasing working memory load diminishes attentional inhibition efficiency in individuals with high trait anxiety. Interestingly, however, their results revealed that threatening distractor only reduced anxious individuals' attentional inhibition under low cognitive load, but not under high cognitive load. Berggren and colleagues suggested that Pessoa's (2010) hypothesis about the interactions between emotion and cognition may account for this finding. Pessoa (2009, 2010) pointed out that processing of affective stimuli may compete for resources with other cognitive processes such as executive functions. Thus, anxious individuals may reduce the processing of threatening stimuli when the working memory load is heavy.

On the other hand, other studies have found that high cognitive load facilitates attentional control in individuals with subclinical anxiety (e.g., Najmi, Amir, Frosio, & Ayers, 2015). Basanovic et al. (2018) showed that cognitive load enhanced inhibitory attentional control. However, the effects of cognitive load on attentional control were not significantly different between the high and low anxious groups. Soares, Rocha, Neiva, Rodrigues, and Silva (2015) found that SA individuals were more likely to be distracted by task-irrelevant threat-related stimuli (e.g., angry faces) and take a longer time to detect a target in a visual search task under high cognitive load. However, they demonstrated better task accuracy than NA individuals.

This finding implies that SA individuals may expend more effort toward goal achievement under high cognitive load. Consequently, they take more time to respond but demonstrate better performance effectiveness than their NA counterparts. The beneficial effects of cognitive load on attentional inhibition (i.e., less interference from distractors) have also been observed in individuals with subclinical anxiety and generalized anxiety disorder (Najmi et al., 2015). Moreover, when required to inhibit threat-related distractors under high cognitive load, patients with SAD demonstrate greater activation in the rostral anterior cingulate cortex (ACC) than health controls (Wheaton, Fitzgerald, Phan, & Klumpp, 2014). This suggests that a compensatory mechanism may counteract the harmful effects of high cognitive load on attentional inhibition and keep task performance intact in SA individuals.

The inconsistencies among the aforementioned findings may also be attributable to differences in the tasks used to measure attentional control and the strategies used to manipulate cognitive load. For example, Soares et al. (2015) used the visual search task, which assesses attentional bias rather than attentional control ability. With regard to the cognitive load manipulation, Berggren et al. (2012) asked participants to complete a secondary auditory discrimination task while performing the antisaccade task. This secondary task required immediately perceptual discrimination rather than working memory capacity, which commonly refers to the ability to temporarily keep and manipulate information in mind (Cantor & Engle, 1993). Similarly, McKendrick et al. (2018) used social-evaluative primes to increase social-cognitive load during the emotional antisaccade task. This procedure induced anxiety of being evaluated rather than increased demands on working memory. Therefore, working memory load may not be adequately manipulated in either of these studies. Thus, the question of whether working memory load diminishes or boosts attentional inhibition in SA individuals in the presence of threat-related distractors may be required to be further examined.

In this study, an emotional antisaccade task was used to measure attentional inhibition when emotional distractors (neutral, happy, and angry faces) were displayed. The *n*-back task, which is commonly used to assess working memory capacity (Owen, McMillan, Laird, & Bullmore, 2005; Segal, Kessler, & Anholt, 2015), was added to the emotional antisaccade task to manipulate the working memory load. In the *n*-back task, participants are asked to decide whether the currently presented stimulus is identical to the stimulus presented *n* trials (e.g., 1-back, 2-back) before. To achieve the task goal, participants need to retain the presentations of recently presented items temporarily, assess the similarity and difference between two items, and continuously update the target compared to the current item. Accordingly, this task requires the ability to both maintain and manipulate information in working memory. The *n*-back task has been suggested to be a valid manipulation of working memory load (Judah et al., 2013). The current study manipulated low and high working memory load by adding a *1*-back and *2*-back task, respectively, to the emotional antisaccade task.

According to ACT (Eysenck et al., 2007), increased working memory load will impair inhibitory attentional control because of competition for executive attentional resources. Therefore, it was predicted that participants would exhibit reduced inhibitory attentional control (i.e., longer antisaccade latencies and higher error rates on antisaccade trials) in the high cognitive load condition than the low cognitive load condition. Furthermore, the adverse effects of high cognitive load (working memory demands) on inhibitory attentional control are assumed to be greater in SA individuals than in NA individuals. It was predicted that when compared to NA participants, the cognitive load would result in a more significant decline in inhibitory attentional control in SA participants. ACT also expects that the presence of threat-related stimuli (e.g., angry faces) will exaggerate impairments in inhibitory attentional control in SA individuals. Thus it was predicted that SA participants would demonstrate reduced inhibitory attentional control for threat-related stimuli relative to NA participants. Moreover, SA participants would show poorer inhibitory attentional control for threat-related stimuli under high cognitive load than under low cognitive load.

2. Method

2.1. Participants

A total of 1228 undergraduate students completed a brief screening survey, which included the straightforward version of the Social Interaction Anxiety Scale (*S*-SIAS; Rodebaugh, Woods, & Heimberg, 2007). The *S*-SIAS includes only the 17 straightforward items of the full version of the SIAS (Mattick & Clarke, 1998). Participants with *S*-SIAS scores that fell within the highest quartile (≧33) constituted the SA group, whereas those with scores that fell equal to or below the mean (≦24) constituted the NA group. Thirty-six SA (23 women; $M_{\text{age}} = 21.11$, $SD = 1.24$) and thirty-six NA (22 women; $M_{\text{age}} = 20.75$, $SD = 1.42$) participants volunteered to participate in this study. Group differences in age, $t(70) = 1.15$, $p = .25$, and sex ratios, $\chi^2(1, N = 72) = 0.06$, $p = .80$, were not significant. As a part of the experiment, the participants completed the full version of the SIAS, Brief Fear of Negative Evaluation Scale (BFNE; Leary, 1983), State-Trait Anxiety Inventory-Trait (STAI-T; Speilberger, Gorsuch, Lushene, Vagg, & Jocobs, 1983) and Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996). Participant characteristics are presented in Table 1. As shown in Table 1, SA participants reported higher levels of social anxiety (i.e., the SIAS and BFNE), trait anxiety (i.e., the STAI-T), and depressive symptoms (i.e., the BDI-II) than NA participants.

2.2. Self-report inventories

The SIAS (Mattick & Clarke, 1998) consists of 20 items, each of which is rated on a 5-point (0–4) Likert scale. It is a commonly used measure of fear of situations that involve social interaction. The *S*-SIAS (Rodebaugh et al., 2007) includes only the 17 straightforward SIAS items. The scores yielded by the two versions have been shown to be strongly correlated ($r = 0.97$; Heidenreich, Schermelleh-Engel, Schramm, Hofmann, & Stangier, 2011). The Chinese version of the SIAS has demonstrated good internal consistency ($\alpha = 0.90$–0.92) and acceptable validity (C.-H. Chang, 2020; Yang, 2003). In this study, the Cronbach's alphas of the SIAS and *S*-SIAS were both 0.94.

Table 1
Mean and standard deviation for self-report inventories.

	SA group ($n = 36$)	NA group ($n = 36$)	t (70)
	M (*SD*)	*M* (*SD*)	
S-SIAS (screening)	46.53 (6.91)	8.86 (2.87)	30.19***
SIAS	53.06 (7.52)	13.03 (4.42)	27.53***
BFNE	50.17 (5.66)	38.03 (9.38)	6.65***
STAI-T	50.33 (8.86)	34.33 (11.61)	6.57***
BDI-II	14.17 (7.70)	8.19 (6.90)	3.47**

Note: SA group = socially anxious group; NA group = non-anxious group; *S*-SIAS = Straightforward version of the Social Interaction Anxiety Scale; SIAS = Social Interaction Anxiety Scale; BFNE = Brief Fear of Negative Evaluation Scale; STAI-T = State-Trait Anxiety Inventory-Trait; BDI-II = Beck Depression Inventory-II. $^{**}p < .01$. $^{***}p < .001$.

The 12-item BFNE (Leary, 1983) assesses apprehensions about receiving negative evaluations from others. Each item is rated on a 5-point (1–5) Likert scale. The BFNE has exhibited high internal consistency ($\alpha = 0.90$- 0.97) and good validity (Collins, Westra, Dozois, & Stewart, 2005; Leary, 1983). The Chinese version of the BFNE has also demonstrated good internal consistency (α = 0.88; Liang, 2018). Cronbach's alpha in this study was 0.93.

The 20-item STAI-T (Speilberger et al., 1983) assesses one's tendency to respond to a wide range of daily situations with anxiety. Each item is rated on a 4-point (1–4) Likert scale. The STAI-T has good reliability ($\alpha = 0.88$) and validity (Stanley, Beck, & Zebb, 1996). The Chinese version of the STAI-T has also demonstrated excellent internal consistency ($\alpha = 0.93$) and good construct validity (Chung & Long, 1984). In this study, Cronbach's alpha of the STAI-T was 0.95.

The 21-item BDI-II (Beck et al., 1996) measures the severity of depressive symptoms experienced during the past two weeks. Each item is rated on a 4-point (0–3) Likert scale. The BDI-II has demonstrated excellent reliability and good validity (Beck et al., 1996). The Chinese version of the BDI-II has been shown to have acceptable internal consistency ($\alpha = 0.86$- 0.90) and good construct validity (H. Chang, 2005; S.-Y. Chen, 2000; Liang, 2018). Cronbach's alpha of the BDI-II in this study was 0.94.

2.3. Cognitive-load antisaccade task

The antisaccade task was used to assess inhibitory attentional control. Low and high cognitive load were manipulated by adding a secondary *1*-back or *2*-back task, respectively, to the primary emotional antisaccade task. There were 6 blocks in each cognitive load condition (3 prosaccade and 3 antisaccade blocks), each of which included 24 trials. Thus, a total of 288 trials were conducted. To ensure that participants understood the task, 24 practice trials (12 prosaccade and 12 antisaccade trials) were conducted before each condition.

Before each trial, a drift-correction point subtending 0.6° of visual angle (0.6 cm in diameter) was displayed at the center of the screen. Participant were asked to fixate on this point and press the spacebar to initiate the presentation of a central cue for 300 ms. In the prosaccade blocks, the central cue was the word "Toward", which instructed participants to look *at* the target. In the antisaccade blocks, the central cue was the word "Away", which instructed participants to direct the gaze *away* from the target and toward its mirror position on the screen. The cue words were presented in different colors (red, blue, green, yellow, purple, or white) against a black background. After the disappearance of the cue, a face was presented on either the right or left side of the screen for 600 ms. The participants were required to make either a prosaccade or an antisaccade as quickly and accurately as possible. After the participants made a saccadic response, a white circle was displayed at the center of the screen. This white circle was used to remind the participants to provide a key-press response. In the high cognitive load condition, the participants were required to indicate whether the color of the cue presented in the current trial (trial *N*) was the same as the color of the cue that appeared two trials earlier (trial *N*-2). In the low cognitive load condition, the participants were required to indicate whether the color of the cue presented in the current trial (trial *N*) was the same as the color of the cue that appeared in the previous trial (trial *N*-1). The participants were instructed to press the key "p" with their right index finger to indicate "same" or press the key "q" with their left index finger to indicate "different". The white circle was displayed on the screen until the participant provided a key-press response or for a maximum duration of 2000 ms, followed by a 500-ms inter-trial interval. All the participants completed both high and low cognitive load conditions. The order of the conditions was randomized for each participant. The sequence of the prosaccade (A) and antisaccade (B) blocks in each condition was either ABABAB or BABABA. The order of the two sequences was counterbalanced across conditions and participants.

2.4. Apparatus and stimuli

The EyeLink 1000 Plus eye-tracking system (SR Research Ltd., Mississauga, Canada) was used to record eye movements. Participants' gaze positions were recorded at a 1000-Hz sampling rate with up to 0.25° accuracy and 0.01° spatial resolution. The experiment was created using SR Research Experiment Builder (SR Research Ltd., Mississauga, Canada). The stimuli were displayed on a 17-inch LCD color monitor with a resolution of 1024 × 768 pixels. The refresh rate of the monitor was 60 Hz.

The face stimuli used in this study were selected from the Taiwan corpora of Chinese emotions and relevant psychophysiological data: A college student database of facial expressions for basic emotions (Shyi, Huang, & Yeh, 2013), which contains a standardized set of emotional faces. A total of 24 photographs which included 8 characters (4 women and 4 men) with angry, happy, and neutral expressions were selected for this study. All these photographs were validated in a previous study by Liang et al. (2017). Specifically, happy faces were perceived to be more pleasant than both angry and neutral faces, and neutral faces were perceived to be more pleasant than angry faces. External features such as ears and hair were removed from each face. Each face subtended a horizontal and vertical visual angle of 4.06 ° × 5.13 ° (4.25 cm wide and 5.38 cm high) and was displayed 11.60° (12.19 cm) from the fixation point to the center of the picture.

2.5. Procedure

This study was approved by the Research Ethics Committee of National Taiwan University. After providing informed consent, the participants were seated approximately 60 cm away from a computer monitor, and a chinrest was used to restrain their head movements. Next, task instructions were displayed on the monitor. Following a 9-point calibration sequence, the participants performed the cognitive-load antisaccade task. After the participants completed this task, they responded to the SIAS, BFNE, STAI-T, and BDI-II. The duration of the experiment was approximately 1 h and each participant received $300 NTD (equivalent to $10 USD) as compensation for participation.

2.6. Data preparation and statistical analyses

Eye movement data were processed using EyeLink Data Viewer (SR Research Ltd., Mississauga, Canada). Dependent variables include latencies of correct saccades and percentages of erroneous saccades (i.e., error rate). Saccade onset was determined when velocity exceeded 30°/s and the acceleration exceeded $8000°/s^2$. Saccade latency was defined as the interval between the presentation of the face and onset of the first correct saccade. Trials in which a blink occurred before the saccade (Jazbec, McClure, Hardin, Pine, & Ernst, 2005), or the eye tracker failed to track pupil or corneal reflection were excluded from analysis. Anticipatory saccades with latencies shorter than 80 ms (Simó, Krisky, & Sweeney, 2005) and late saccades with latencies longer than 600 ms were also excluded from the final analysis (Ansari & Derakshan, 2010). These criteria resulted in a loss of 6.77% of the prosaccade trials and 6.60% of the antisaccade trials in the low cognitive load condition, and 6.77% of the prosaccade trials and 5.56% of the antisaccade trials in the high cognitive load condition.

Because depression has been found to be associated with deficits in attentional control, the BDI-II scores were included as covariates in analysis of covariance (ANCOVA) models (Ainsworth & Garner, 2013). To check the effectiveness of the cognitive load manipulation, a two-way (group: SA, NA) × (cognitive load: low cognitive load, high cognitive load) repeated measures ANCOVA with the BDI-II scores as covariates was conducted to examine differences in the accuracy on the *n*-back tasks. The four-way mixed repeated measures ANCOVAs with group (SA, NA) as the between-subjects factor, and cognitive load (low cognitive load, high cognitive load), trial type (prosaccade, antisaccade) and face type (angry, happy, neutral) as within-subjects factors were conducted to examine differences in the latencies of correct saccades and saccade error rates, while controlling for the BDI-II scores.

3. Results

The results of ANCOVAs showed that there were no significant main effects or interaction effects involving the BDI-II on the accuracy of the *n*-back task, or on latencies and error rates of cognitive-load antisaccade task. Therefore, we only reported the results of analysis of variance (ANOVA) models without controlling for the BDI-II in the results section.

3.1. Manipulation check for cognitive load

The main effect of cognitive load was significant, $F\,(1, 70) = 44.17$, $p < .001$, $\eta_p^2 = 0.39$, indicating a lower accuracy in the high cognitive load ($M = 78.33\%$, $SD = 7.36$) than in the low cognitive load condition ($M = 84.38\%$, $SD = 7.85$). The main effect of group was not significant, $F\,(1, 70) = 1.06$, $p = .31$, $\eta_p^2 = 0.02$. The interaction effect of group by load was not significant, $F\,(1, 70) = 0.05$, $p = .82$, $\eta_p^2 < 0.01$. The results of manipulation check suggested that the task was a successful manipulation of cognitive load.

3.2. Latencies of correct saccade

Means and standard deviations for latencies of correct saccades are shown in Table 2. The main effect of trial type was significant, $F\,(1, 70) = 168.49$, $p < .001$, $\eta_p^2 = 0.71$, indicating a longer saccade latencies for antisaccade trials ($M = 257.99$, $SD = 29.30$) than for prosaccade trials ($M = 213.15$, $SD = 23.72$). The interaction effect between group and cognitive load was significant, $F\,(1, 70) = 5.21$, $p = .025$, $\eta_p^2 = 0.07$. However, this interaction was further qualified by a significant three-way interaction between group, cognitive load and trial type, $F\,(1, 70) = 6.03$, $p = .017$, $\eta_p^2 = 0.08$. To further examine this three-way interaction, the group × cognitive load ANOVAs were conducted separately for prosaccade and antisaccade trials (Fig. 1). For the prosaccade trials, no significant main or interaction effects were found ($ps > .05$). However, with regard to the antisaccade trials, the interaction effect between group and cognitive load was significant, $F\,(1, 70) = 12.73$, $p = .001$, $\eta_p^2 = 0.15$. Follow-up analyses revealed the SA group ($M = 245.70$, $SD = 29.99$) had shorter antisaccade latencies than the NA group ($M = 262.39$, $SD = 29.16$) under high cognitive load, $t\,(70) = -2.40$, $p = .019$, $d = 0.56$, but not under low cognitive load, $t\,(70) = -\,0.32$, $p = .75$, $d = 0.08$. Moreover, among SA participants, antisaccade latencies were shorter under high cognitive load ($M = 245.70$, $SD = 29.99$) than under low cognitive load ($M = 260.76$, $SD = 30.50$), $t\,(35) = -6.06$, $p < .001$, $d = 1.01$. However, there were no differences in antisaccade latencies

Table 2
Mean and standard deviation for latencies of correct saccades.

	SA group ($n = 36$)		NA group ($n = 36$)	
	Low load	High load	Low load	High load
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Prosaccade				
Angry face	208.47 (22.75)	204.78 (29.33)	212.14 (23.33)	215.82 (33.11)
Happy face	214.80 (25.77)	213.58 (31.43)	220.53 (27.89)	211.82 (27.68)
Neutral face	214.32 (22.28)	210.03 (30.65)	216.88 (26.52)	214.64 (31.42)
Antisaccade				
Angry face	260.11 (34.58)	241.78 (39.26)	267.08 (42.68)	264.61 (38.10)
Happy face	260.46 (33.95)	246.46 (34.18)	263.64 (30.53)	261.26 (29.07)
Neutral face	261.71 (32.50)	248.84 (34.21)	258.61 (33.18)	261.32 (29.72)

Note: SA group = socially anxious group; NA group = non-anxious group.

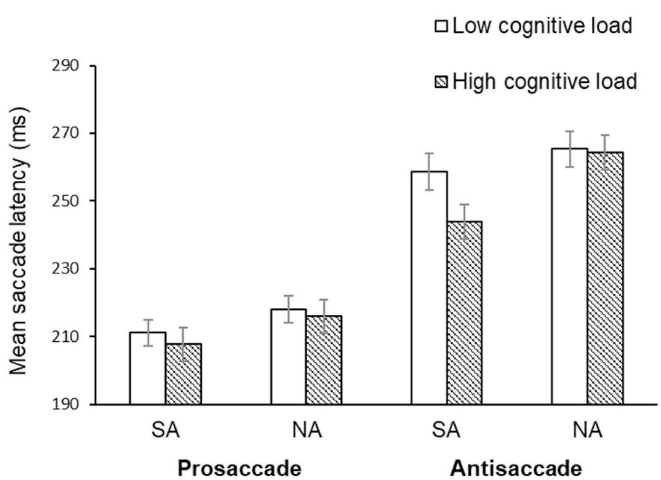

Fig. 1. Mean prosaccade and antisaccade latencies under low and high cognitive load in SA and NA participants.

between the two cognitive load conditions among NA participants, t (35) = - 0.22, p = .823, d = 0.04.

In addition, there was a significant interaction effect between group and face type, F (2, 140) = 3.32, p = .039, $\eta_p^2 = 0.05$. Follow-up analyses revealed that, among SA participants, overall saccade latencies for angry faces (M = 228.79, SD = 23.85) were shorter than for happy faces (M = 233.82, SD = 22.92) and neutral faces (M = 233.73, SD = 23.29), F (2, 70) = 3.83, p = .026, $\eta_p^2 = 0.10$. There were no differences in saccade latencies between different face types among NA participants, F (2, 70) = 0.56, p = .57, $\eta_p^2 = 0.02$. No other significant main effects or interaction effects were found ($ps > .05$).

3.3. Saccade error rate

Means and standard deviations for saccade error rates are shown in Table 3. The main effect of group was not significant, F (1, 70) = 0.60, p = .44, $\eta_p^2 < 0.01$. The main effects of cognitive load, F (1, 70) = 13.45, p < .001, $\eta_p^2 = 0.16$, and trial type, F (1, 70) = 82.95, p < .001, $\eta_p^2 = 0.54$, were significant. Erroneous saccades were made more frequently in the high cognitive load condition (M = 13.35%, SD = 8.64) than in the low cognitive load condition (M = 10.8%, SD = 6.08). Participants also made more erroneous saccades on antisaccade trials (M = 18.10%, SD = 11.52) than on prosaccade trials (M = 6.05%, SD = 4.88). Importantly, a three-way interaction between group, cognitive load, and trial type

Table 3
Mean and standard deviation for saccade error rates (%).

	SA group ($n = 36$)		NA group ($n = 36$)	
	Low load	High load	Low load	High load
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Prosaccade				
Angry face	4.58 (3.84)	6.72 (7.23)	6.46 (5.18)	8.52 (8.26)
Happy face	6.37 (5.93)	5.76 (8.25)	5.79 (5.29)	9.23 (10.05)
Neutral face	3.82 (4.60)	4.45 (9.10)	5.09 (4.58)	5.78 (8.56)
Antisaccade				
Angry face	16.91 (9.85)	23.48 (17.50)	20.56 (13.58)	19.33 (13.51)
Happy face	16.55 (10.70)	17.82 (13.27)	18.63 (11.02)	18.18 (13.67)
Neutral face	10.76 (9.92)	20.12 (18.41)	14.12 (13.07)	20.77 (17.31)

Note: SA group = socially anxious group; NA group = non-anxious group.

reached marginal significance, F (1, 70) = 3.90, p = .052, $\eta_p^2 = 0.05$. To further examine this three-way interaction, the group × cognitive load ANOVAs were conducted separately for prosaccade and antisaccade trials (Fig. 2). For the prosaccade trials, no significant main or interaction effects were emerged ($ps > .05$). However, with regard to the antisaccade trials, the interaction effect between group and cognitive load was marginally significant, F (1, 70) = 3.45, p = .067, $\eta_p^2 = 0.07$. Planned comparisons showed that, among SA participants, the error rate on antisaccade trials was significantly higher in the high cognitive load condition (M = 20.47%, SD = 15.00) than in the low cognitive load condition (M = 14.74%, SD = 9.10), t (35) = 3.65, p = .001, d = 0.61. However, there were no differences in error rate on antisaccade trials between the two cognitive load conditions among NA participants, t (35) = 1.08, p = .29, d = 0.18.

The main effect of face type was significant, F (2, 140) = 13.68, p < .001, $\eta_p^2 = 0.16$, indicating that overall saccade error rates were greater for angry faces (M = 13.32%, SD = 6.84) than for happy (M = 12.29%, SD = 6.83) and neutral faces (M = 10.62%, SD = 8.22) ($ps < .05$). The three-way interaction of group, cognitive load and face type was also significant, F (2, 140) = 3.36, p = .038, $\eta_p^2 = 0.05$. Follow-up analyses revealed that both the SA group, F (2, 70) = 16.96, p < .001, $\eta_p^2 = 0.33$, and the NA group, F (2, 70) = 7.42, p = .001, $\eta_p^2 = 0.18$, had higher saccade error rates for angry and happy faces than for neutral faces in the low cognitive load condition. In the high cognitive load condition, in contrast, the SA group demonstrated higher saccade error rates for angry faces than for happy and neutral faces, F (2, 70) = 4.65, p = .013, $\eta_p^2 = 0.12$, while the NA group showed no differences in the saccade error rates between different face types, F (2, 70) = 0.20, p = .82, $\eta_p^2 < 0.01$.

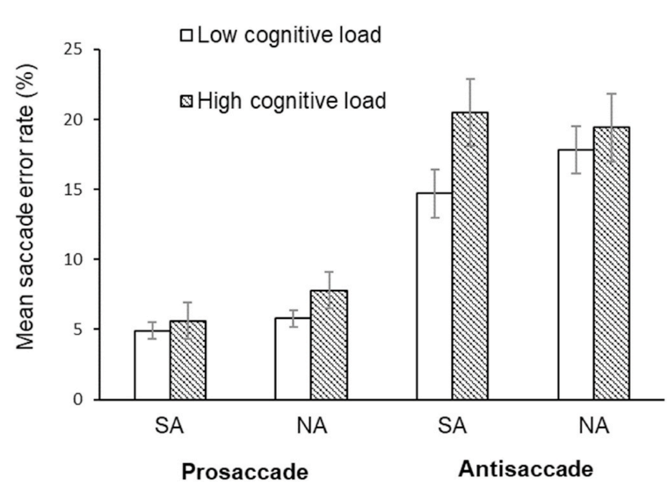

Fig. 2. Mean prosaccade and antisaccade error rates under low and high cognitive load in SA and NA participants.

4. Discussion

This study investigated whether cognitive load hampers inhibitory attentional control in SA individuals when exposed to emotional stimuli. The results showed that overall, participants had higher saccade error rates under high cognitive load than low cognitive load. This finding suggests that cognitive load reduced individuals' general cognitive performance. More importantly, as predicted, the results revealed that cognitive load had a more significant impact on inhibitory attentional control among SA participants than among NA participants.

In this study, SA participants showed shorter antisaccade latencies under high cognitive load than under low cognitive load. However, this difference in antisaccade latencies between the two cognitive load conditions was not observed among NA participants. This finding indicates that cognitive load improves the efficiency of inhibitory attentional control in SA individuals. Furthermore, among SA participants, error rates on antisaccade trials were higher in the high cognitive load condition than in the low cognitive load condition. This indicates that cognitive load reduces the effectiveness of inhibitory attentional control in SA individuals. Contrastingly, the cognitive load had no significant impact on inhibitory attentional control among NA participants. These findings suggest that cognitive load facilitates efficiency but impedes the effectiveness of inhibitory attentional control in SA individuals but not NA individuals.

In addition, both SA and NA participants made more erroneous saccades for angry and happy faces than neutral faces under low cognitive load. Under high cognitive load, SA participants made more erroneous saccades for angry faces than happy and neutral faces. Conversely, NA participants showed no differences in error rates among different face types. Regardless of cognitive load levels, SA participants had shorter saccade latencies for angry faces than happy and neutral faces, while NA participants showed no differences in saccade latencies among different face types. These results partially supported our hypothesis that the presence of threat-related stimuli has a stronger impact on attentional control performance among SA participants than NA participants. These findings mentioned above will be discussed in more detail in the following paragraphs.

The current study found that cognitive load improved efficiency but diminished the effectiveness of inhibitory attentional control among SA individuals. In contrast, the cognitive load had no significant effects on inhibitory attentional control among NA individuals. The findings are inconsistent with the ACT's prediction and previous research. ACT posits that cognitive load can amplify attentional control deficits in anxious individuals because of competition for cognitive resources within the top-down attentional control system (Eysenck et al., 2007). Thus, a high cognitive load was expected to negatively impact the effectiveness and efficiency of inhibitory attentional control among SA individuals. Soares et al. (2015) used the letter discrimination task with distracting emotional stimuli to examine the effects of cognitive load on attentional control in SA individuals. They found that SA participants made slower but more accurate responses under high cognitive load than under low cognitive load when compared to NA participants. Their findings suggest that SA individuals have to expend more effort to resist interference from distracting stimuli and make correct responses under high cognitive load when compared to NA individuals. This indicates that SA individuals may successfully overcome the negative impact of high cognitive load on the effectiveness (rather than the efficiency) of inhibitory attentional control by adopting compensatory strategies (Eysenck & Derakshan, 2011). However, opposite results were observed in the current study.

The results of the current study are consistent to some extent with Basanovic et al.'s (2018) work that supported cognitive load improves inhibitory attentional control efficiency. However, unlike the current study, they failed to find that cognitive load would disproportionately adversely influence attentional control among anxious individuals compared to NA individuals. Moreover, they also did not observe the impact of cognitive load on attentional control effectiveness (i.e., accuracy). A factor that helps to interpret these inconsistencies is the manipulation of cognitive load.

Similar to the current study, Basanovic et al. (2018) used an emotional antisaccade task as the primary task and a memory task that required participants to remember a set of digits for later recognition as the secondary task. In the high cognitive load condition, the digit set consisted of six different digits (e.g., 123456); in the low cognitive load condition, the digit set consisted of six repeated digits (e.g., 333333). This secondary task required participants to remember a digit set, and later participants were asked to decide whether a probe (i.e., a single-digit) that presented on the screen belonged to the preceding digit set or not. Participants may rely on visual maintenance (perceptual processing) rather than verbal rehearsal in working memory (cognitive processing) to complete this task.

Contrastingly, the secondary task used in the current study may be involved in both perceptual and cognitive processing. On the one hand, the *n*-back task used in the current study required participants to decide whether the color (i.e., perceptual processing) of the cue in the current trial was the same as the cue presented one or two trials before. On the other hand, the *n*-back task also required participants to retain, manipulate and update information in the working memory (cognitive processing). Previous studies have suggested that increased perceptual load facilitates attentional performance whereas heightened cognitive load diminishes attentional performance (Lavie, 2010; Lavie, Hirst, de Fockert, & Viding, 2004). It is plausible that the cognitive load manipulation in the present study increased both perceptual and cognitive loads, resulting in the improvement of attentional control efficiency indexing by shorter saccade latencies and the impairment of attentional control effectiveness indexing by elevated error rates on antisaccade trials. Furthermore, the current study provides evidence that heightened cognitive load disproportionately affects inhibitory attentional control among SA individuals compared with NA individuals.

Moreover, the findings may be explained by the compensatory strategies used by SA participants. In this study, SA participants may have expended more effort in the high cognitive load condition than in the low cognitive load condition to maintain their task performance by recruiting more top-down attentional control resources and trying to make saccadic responses as fast as they could (Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Wheaton et al., 2014). Consequently, high cognitive load facilitated SA participants to make faster antisaccade latencies (indicating better efficiency). However, high cognitive load also resulted in more erroneous saccades on antisaccade trials (indicating failures of inhibitory attentional control) in SA participants. The present findings suggest that SA individuals may be more vulnerable to the adverse effects of cognitive load on inhibitory attentional control than NA individuals. Moreover, the strategies used by SA individuals may not always be sufficiently effective to compensate for the adverse effects of cognitive load.

An alternative explanation is that cognitive load facilitates the executive control of attention in SA individuals, consequently, leads to the reallocation of attentional resources (Arnau, Wascher, & Kuper, 2019). According to ACT, anxious individuals tend to allocate more attentional resources than NA individuals to monitor and detect threat-related stimuli even when these stimuli are absent (Eysenck et al., 2007). This tendency is associated with an overactive bottom-up threat detection system and an underactive top-down goal-directed system, contributing to the maintenance of anxiety (Mogg & Bradley, 1998). However, when task demands on cognitive resources increase, greater cognitive load may facilitate the executive control of attentional resources in SA individuals (Vytal et al., 2012, 2013).

SA individuals may redirect cognitive resources from threat-related stimuli to current task demands under high cognitive load. This weakens the adverse effects of anxiety on attentional control and improves inhibitory attentional control efficiency. However, why was the effectiveness of inhibitory attentional control poorer? It is possible that

SA individuals allocate less attentional resources to error monitoring which plays an essential role in regulating cognitive functions such as sustained attention and attentional control (Senderecka, 2018; Xiao et al., 2015; Yeung & Cohen, 2006), thus leading to a higher error rate on antisaccade trials.

Participants of both groups had higher saccade error rates for emotional faces than neutral faces under low cognitive load. Nevertheless, under high cognitive load, only SA participants revealed higher saccade error rates for angry faces than happy and neutral faces. The findings were consistent with a framework describing the interaction and competition mechanisms between cognition and emotion by Pessoa (2009, 2010). When the cognitive load was low, participants exhibited biased processing in favor of the emotion-laden stimuli (including positive and negative stimuli). Processing emotional stimuli may compete for cognitive resources with attentional control and lead to elevated saccade error rates for emotional faces among all participants. Nevertheless, SA participants did not show higher saccade error rates than NA participants because sufficient cognitive resources were available.

However, heightened cognitive load attenuated processing bias for emotional stimuli in NA participants because the working memory resources were heavily occupied. It is worth noting that SA participants had higher saccade error rates for angry faces than happy and neutral faces in the high cognitive load condition. This suggests that SA individuals may have difficulty inhibiting the processing of threat-related stimuli compared to NA participants.

Interestingly, the present study showed that SA participants had shorter saccade latencies for angry faces than happy and neutral faces. However, NA participants did not show differences in saccade latencies among different face types. This finding suggests that threat-related stimuli can speed up saccadic responses in SA participants. This finding is consistent with the vigilance-avoidance hypothesis, which predicts that SA individuals will demonstrate automatic vigilance toward social threat-related stimuli and rapidly redirect their attention away from them (Mogg, Bradley, Miles, & Dixon, 2004; Pflugshaupt et al., 2005; Vassilopoulos, 2005). Prosaccade latencies for angry faces were faster among SA individuals because of their attentional vigilance toward social threat. Conversely, they made faster antisaccades away from angry faces because of rapid attentional avoidance following early attentional vigilance. Weierich, Treat, and Hollingworth (2008) have noted that an initial orientation to threat does not necessarily rely on overt attentional shifts (i.e., eye movement). Thus, when SA participants were required to make antisaccades in response to angry faces, they may have first automatically and covertly oriented their attention toward the face. Immediately after this they shifted their attention away from the face and made a correct antisaccade response.

The present findings have important implications for interventions that aim to improve goal-directed attentional control in SA individuals. First, whether SA individuals can maintain task performance under high cognitive load depends on the successful and efficient reallocation of attentional resources rather than merely the expenditure of more effort. Therefore, SA individuals should reallocate most attentional resources toward the goal-directed tasks rather than threat-related stimuli to maintain the efficiency of inhibitory attentional control under high cognitive load. Accordingly, the present findings suggest that future interventions for social anxiety should aim to enhance attentional control in SA individuals by improving their ability to reallocate attentional resources under high cognitive load efficiently. Improving resource allocation can reduce vigilance toward social threat-related stimuli, and consequently alleviate social anxiety (Malinowski, 2013). Second, the present findings suggest that error-detection and error-monitoring capacities play a critical role in the execution of inhibitory attentional control (Senderecka, 2018; Yeung, Botvinick, & Cohen, 2004). Walsh, Buonocore, Carter, and Mangun (2011) have suggested that when performing an attentional task, the interaction between the ACC, which is a brain region involved in error-detection, and the frontoparietal attentional control network contributes to an improvement in task performance in subsequent trials.

There are several limitations in this study. First, this study used a non-clinical sample of undergraduate students with high and below-average social anxiety levels. Thus, the present findings may not be generalizable to individuals with a diagnosis of SAD. Future studies should replicate these findings among patients with SAD. Second, the current study did not include measures of state anxiety. Thus it is unclear whether the cognitive load has impacts on participants' levels of state anxiety. Future studies should include measures of subjective anxiety levels and physiological symptoms of anxiety to examine the effects of cognitive load on anxiety. Third, we speculated that cognitive load would facilitate attentional inhibition efficiency through resource reallocation rather than greater effort expenditure. However, we did not assess whether more efforts were expended and whether resource reallocation had occurred. Therefore, it is difficult to establish the validity of these speculative explanations. Future studies should combine behavioral and neuroimaging measures to explore the neurocognitive mechanisms that underlie the effects of cognitive load on inhibitory attentional control.

In summary, this study adopted a novel dual-task paradigm that combined an emotional antisaccade task and *n*-back tasks to examine the effects of low and high cognitive load on attentional inhibition among SA and NA individuals. The present findings indicate that SA individuals reallocate attentional resources to cope with increased task demands under high cognitive load. SA individuals may reallocate more resources to the top-down (goal-directed) attentional control system instead of the bottom-up (stimulus-driven) system. This may enhance the efficiency of inhibitory attentional control (i.e., as indicated by shorter antisaccade latencies). However, inadequate allocation of attentional resources to error detection may result in failures to execute inhibitory attentional control, as evidenced by higher error rates on antisaccade trials among SA individuals. The present findings highlight the importance of providing training to enhance goal-directed attentional control, particularly resource reallocation capacities, as a part of interventions for social anxiety. Recent research also suggests that enhancing goal-directed cognitive control functions may be a key component of attention bias modification training, a new treatment for anxiety disorders (Bar-Haim, 2010; Heeren, Mogoase, McNally et al., 2015; Mogg & Bradley, 2018). Future studies should examine the effects of interventions that directly target inhibitory attentional control in individuals with high social anxiety or SAD. The present study also suggests that cognitive load may play a crucial role in inhibitory attentional control training because high task demands will trigger resource reallocation in SA individuals (Vytal et al., 2012, 2013).

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Declarations of interest

The author declares no conflict of interest.

Author declaration

I am the only one author (also the corresponding author) of this manuscript, and I hereby warrant that the following declarations made are true:

I wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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CRediT authorship contribution statement

Chi-Wen Liang: Conception and design of study, Analysis and interpretation of data, Drafting the manuscript, Critical revision.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2021.103925.

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