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How Does Anxiety Affect Cognitive Control? Proactive and Reactive Control Under State Anxiety

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HOW DOES ANXIETY AFFECT COGNITIVE CONTROL?

PROACTIVE AND REACTIVE CONTROL UNDER STATE ANXIETY

by

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ABSTRACT

HOW DOES ANXIETY AFFECT COGNITIVE CONTROL?
PROACTIVE AND REACTIVE CONTROL UNDER STATE ANXIETY

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The University of Wisconsin-Milwaukee, 2018
Under the Supervision of Christine L. Larson

Cognitive control is a construct that prioritizes how we process stimuli and information and execute behaviors to flexibly and efficiently adapt to internal goals and external environmental changes. A recent theory, the Dual Mechanism of Control (DMC), distinguishes this phenomenon by two distinct cognitive control operations: proactive control and reactive control (Braver, 2012). Anxiety increases the allocation of attentional and working memory resources to threat-related stimuli, which impairs cognitive performance (Sarason, 1988), but additional work is needed to assess how anxiety impacts these two distinct forms of cognitive control. In this study, I examined how state anxiety affected proactive control, using the AX-continuous performance task (AX-CPT), and reactive control, using the classic Stroop task. The results showed that state anxiety inhibited proactive control in AX-CPT test, but increased reactive control in the Stroop task. Ultimately, by completing this study, we will better understand how anxiety impacts the proactive and reactive control.

To

my parents,

my sisters and brothers,

my friends

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LIST OF ABBREVIATIONS

ACC	Anterior cingulate cortex
ACT	Attentional control theory
AX-CPT AX	Continuous Performance Task
DLPFC	Dorsolateral PFC
DMC	Dual mechanisms of control

ACKNOWLEDGEMENTS

The eight years of my doctoral study from 2010 to 2018 has totally changed my life. I never thought my life will be so unique when I put my foot on the land of the United States. I can still remember the excited smile on my face and I have too many stories to tell. Finally, I am still standing at the end. Thank you all for helping me, I can complete my doctoral study. This doctoral study gives me a chance to think about my life: Which is most important in my life? What to do in my rest of life?

I would like to express the deepest appreciation to my advisor Professor Christine Larson, a respectful advisor and genius of psychology research. You gave me hope and rescued me when I was lost. Without your patience, guidance and persistent help this dissertation would not have been possible. You taught me how to conduct research to a professional standard.

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Thank you to my mother for supporting my study when I was not able to take care of you when you were sick. Thank you to my father for taking care of my mother during those years. Thank you to my sisters for taking care of our whole family.

Introduction

Cognitive control is defined as the process of regulation, coordination and management of thoughts and action in accordance with internally maintained behavioral goals and flexibly responding to salient environmental demands (Braver, 2012). It mainly includes attention, inhibitory control, working memory, cognitive flexibility, planning, reasoning and problem solving (Chan, Shum, Toulopoulou, & Chen, 2008; Diamond, 2013). Cognitive control can help people respond to detected stimuli quickly, override prepotent responses, ignore irrelevant information that interferes with the current task, or perform multiple tasks simultaneously. For example, cognitive control can assist you if you are hungry but you do not have permission to take your roommate's pizza, or if you are looking for your white car in the parking lot, in which case you need to select your car among all the other white cars while ignoring cars of other colors (Miller & Cohen, 2001). In the laboratory, one classic way to index cognitive control is the Stroop task (Stroop, 1935). When a person is instructed to name the colors of the ink or font that the word "GREEN" is presented in (e.g., green or red ink), much more time is required when the color of the ink is incongruent with the meaning of the word (e.g., "green" presented in red ink), compared to when the color of ink matches the printed word. Therefore, cognitive control is important for us to react to important stimuli quickly (such as avoiding danger) and to override distracting task-irrelevant stimuli to stay on task to achieve internal goals.

Due to the ever changing balance of internal goal-directed behavior and stimulus-driven demands of the external environment, cognitive control must be flexible to adapt to changes and execute tasks efficiently. This flexibility allows goal-directed actions to be facilitated and conflicting actions to be suppressed. Cognitive control varies within and across individuals (Braver, 2012). Cognitive control can be changed, developed and improved across the lifespan as it is affected by experience and events (Diamond, 2013). Ideally proactive and reactive control are optimally balanced to appropriately react to salient stimuli, but also complete necessary tasks. At its most adaptive cognitive control is implemented to shift flexibly as the situation demands.

That cognitive control can shift between internally-focused goals and externally-driven stimuli in the same task under different instructions and conditions raises the possibility that there may be two different cognitive control processes. Although many studies have been conducted to clarify these mechanisms (Braver, 2012; Engle & Kane, 2003; Goldman-Rakic, Cools, & Srivastava, 1996; Koechlin & Summerfield, 2007; Miller & Cohen, 2001; Monsell & Driver, 2000; O'Reilly, 2006), research in this area is still in its early stages. A recent theory, the dual mechanisms of control (DMC) attempts to provide a framework for different cognitive control processes by two operational models: proactive control and reactive control (Braver, 2012). Proactive control is conceptualized as a goal-driven system which maintains task-related information in order to bias attention and guide perception and action systems to prepare for the oncoming occurrence of a cognitively demanding event. Reactive control is conceptualized as stimulus-driven control that is mobilized only as needed. When salient stimulus is attended, a transient consequential response can be made. Reactive control is referred to as a ‘late correction mechanism’ by Braver (2012).

The advantage of DMC is that the computational tradeoff based on the benefits and costs of proactive and reactive control allows information to be processed efficiently (Braver, 2012). Under proactive control, a goal can be triggered in advance and maintained until the appearance of a salient stimulus, decreasing internal and external interference, flexibly adjusting and facilitating information processing. However, goal maintenance is costly; it consumes resources and occupies capacity-limited working memory stores, which is required for focal attention (Cowan, 2001; McElree, 2001; Oberauer, 2002). In contrast, under reactive control, goal representation is only active after the onset of a stimulus, which is transient and efficient, but the disadvantage is that attention will be easily reallocated whenever there is a trigger event, which can interrupt the execution of a goal.

The DMC model is supported by neuropsychological and neuroimaging studies (Braver, 2012; Lesh et al., 2013; Paxton, Barch, Racine, & Braver, 2008). The prefrontal cortex (PFC) is important for cognitive control, especially top-down control needed to reallocate attention and execute behaviors towards a goal (Cohen, Dunbar, & McClelland, 1990; Desimone & Duncan, 1995; Miller & Cohen, 2001). The dorsolateral PFC (DLPFC) plays a key role in the maintenance of goals and action execution (Asaad, Rainer, & Miller, 2000; Watanabe, 1990). The ability to mount a sustained pattern of neural activity to maintain a goal has been repeatedly shown in DLPFC in non-human primates (Goldman-Rakic, 1995) and humans (MacDonald, Cohen, Stenger, & Carter, 2000). Conversely, the bottom-up reactivation of task goals is mediated by interference detection and conflict monitoring regions like the anterior cingulate cortex (ACC) (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Patients with schizophrenia who showed impairments of the DLPFC and associated circuitry, such as the parietal cortex, exhibit cognitive control deficits (D. M. Barch, Carter, Braver, & et al., 2001; Cohen, Barch, Carter, & Servan-Schreiber, 1999a; Cohen, Braver, & O'Reilly, 1996; Cohen & Servan-Schreiber, 1992). Based on the DMC theory, proactive control may be represented by sustained activation of the DLPFC, which supports the active maintenance of task goals and facilitates the top-down response to meet cognitive (Cohen, Barch, Carter, & Servan-Schreiber, 1999b) demands. In contrast, reactive control may be reflected as a transient activation of the DLPFC along with heightened recruitment of conflict-monitoring regions, such as the ACC (Braver, 2012; Braver, Paxton, Locke, & Barch, 2009; Kerns et al., 2005; MacDonald et al., 2000). One neuroimaging study found increased DLPFC and parietal activity in proactive versus reactive control in healthy participants (Lesh et al., 2013). In addition, schizophrenia patients with impaired cognitive control did not show significant DLPFC activation in proactive control conditions, but showed similar activation to control subjects during reactive control (Lesh et al., 2013). However, another study found both decreased conflict and error-related activity in the patients'ACC, consistent with impaired reactive control, and no post-conflict or post-error behavioral adjustment was found, suggesting impaired proactive control. It suggests that impaired conflict monitoring in the ACC leads to a deficit in cognitive control by failing to prevent interference of irrelevant information (Kerns et al., 2005). Therefore, the DMC theory is supported by the sustained and transient activation of the DLPFC for proactive and reactive control, respectively, as well as environmentally appropriate engagement of the ACC.

Other studies have also found distinct activation of these two control mechanisms (Braver, 2012) and a shift between these two models under different manipulations (Speer, Jacoby, & Braver, 2003). In Speer's (2003) study, participants were instructed to maintain a short (1 to 6) or long list (6 to 11) of words over a delay then indicate whether the probe words were on the list. In the less demanding short-list block, activation of the left inferior PFC only increased when triggered by a probe word; while in long-list block, lateral PFC activation was sustained during the delay until the probe onset. This suggests that mnemonic processes are preferentially engaged during the delay response period (sustained top-down processing) and retrieval period (transient processing) depending on the task demands.

Many tasks have been used to assess proactive and reactive control. I will focus here on two of the most common, which I propose to use in the current study, the AX Continuous Performance Task (AX-CPT) and the Stroop task. AX-CPT is frequently used to assess proactive control (Braver et al., 2001; Braver, Satpute, Rush, Racine, & Barch, 2005; Locke & Braver, 2008; Paxton et al., 2008). During the AX-CPT, participants are required to make a response to the target probe, which is the letter “X,” but only when it follows the cue letter “A” (target trial). When the probe “X” follows any other letters non-target responses are required. Target trials (AX trials) are presented with high frequency compared to non-target trials. Thus, during these non-target trials, participants must inhibit the prepotent response to the probe “X”. This task measures goal maintenance and updating. All the responses to the probe rely on the memory of the cue letter, which must be maintained during the delay between cue and probe for the rapid target decisions. Therefore, the AX-CPT provides a way to measure the proactive control required for this goal-directed behavior.

The Stroop task (Stroop, 1935) is frequently used to assess reactive control (Gonthier, Braver, & Bugg, 2016; Lesh et al., 2013). In the Stroop task, the color words are presented in congruent or incongruent color inks (e.g. Congruent: the word “GREEN” in green ink; Incongruent: the word “GREEN” in red ink). The participants are instructed to read the words or name the colors. Word reading is faster and more automatic than color naming (MacLeod, 1991). In addition, frequent congruent trials bias participants to respond faster and more accurately rely on word reading. Thus, when the infrequent incongruent trials are presented, participants have to inhibit the strong tendency to read the word and switch to the weaker color naming response to avoid incorrect responses. Unlike the AX-CPT, making a response in the Stroop test does not require contextual information or maintenance of a goal, but simply a reaction to the current stimuli. As expected by this task design, evidence shows that the color naming on incongruent trials in the Stroop task reflects reactive control (Botvinick et al., 2001; Gonthier et al., 2016; Lesh et al., 2013).

Anxiety has been shown to impact cognitive control processes, and some theoretical models suggest that anxiety might differentially impact proactive and reactive control (Eysenck, Derakshan, Santos, & Calvo, 2007; Hu, Bauer, Padmala, & Pessoa, 2012). However, little work has examined its specific impact on these two types of cognitive control (Krug & Carter, 2012; Lamm, Pine, & Fox, 2013). Anxiety is an aversive emotional and motivational state in threatening conditions (Eysenck et al., 2007). The main distinction between its two main types, state and trait anxiety, is that state anxiety is a temporary unpleasant emotional response to some perceived threat, whereas trait anxiety is a personality characteristic in which individuals experience more frequent and more intense anxiety, even in the absence of external threat (Spielberger & Sydeman, 1994). State anxiety increases the allocation of attention resources to threat-related stimuli internally and externally, which was initially posited to impair performance (Sarason, 1988). However, there is also evidence that anxiety does not impair performance (Blankstein, Flett, Boase, & Toner, 1990; Blankstein, Toner, & Flett, 1989). Eysenck and colleagues (2007)'s attentional control theory (ACT) attempted to reconcile this. They proposed that anxiety affects processing efficiency, resulting in the need for compensatory processes to spare performance (Eysenck et al., 2007). Anxiety is thought to impair processing efficiency by restricting the capacity of working memory; indeed high anxiety subjects have been found to have less capacity than those low on anxiety (Darke, 1988). In a working memory test, subjects heard a series of letters or digits then were instructed to report the items in a reverse order, high anxiety subjects performed worse than low anxiety subjects (Moran, 2016). It suggests that goal maintenance in proactive control also depends on working memory. Proactive control, which relies on a goal-directed attentional system is posited to be impaired by anxiety. However, anxiety may lead to a decrease of attentional control, and impairment of inhibition and shifting and that allows for increased reactive control which relies on stimulus-driven attention (Eysenck et al., 2007).

Anxiety may also impact utilization of proactive and reactive control by evaluating benefits and costs to avoid punishment. For example, in a punishment-oriented motivation study, improvement in error rate and RT were predicted by high punishment sensitivity, which suggests these individual utilized proactive control after evaluating the punishment and cost (Savine, Beck, Edwards, Chiew, & Braver, 2010). In a working memory task, Fales et al (2008) found that a negative mood induction led to a shift from sustained to transient activation in working memory regions. Interestingly, this pattern of heightened transient versus sustained activation was evident in high anxious individuals even following a neutral mood induction, in contrast to the sustained working memory area activation in low anxious participants. The authors suggested that due to limited working memory capacity anxiety caused the shifting of attention allocation to unpredictable threats and anxiety-related internal thoughts, thus limiting the availability of working memory for the processing task-irrelevant information. This interferes with maintaining leads ongoing task goals and may impair performance or necessitate more resources to perform appropriately. This suggests a relation between anxiety and utilization of proactive (sustained activity) and reactive (transient activity) control which is consistent with the DMC theory.

Even though some initial evidence suggests anxiety differentially affects proactive and reactive control, more investigation is needed. The differential effect of state anxiety on proactive versus reactive control has not yet been directly compared in the same individuals. The aim of my work is examine how proactive and reactive control will be effected under state anxiety by conducting an AX-CPT and a Stroop task under threat of shock and safety. My hypothesis was: when we induce state anxiety during the AX-CPT test and the Color Naming Stroop test under threat conditions, we would find that proactive control (BX trial type in the AX-CPT) is impaired relative to safe conditions, while reactive control (color naming on incongruent trials in the Stroop task) is increased.

Method

Participants

Seventy-three participants aged 18 to 35 were recruited from the University of Wisconsin-Milwaukee. All participants were granted 2 hours of course extra credit and one $10 gift card. All participants had normal color vision. The sequences of the AX-CPT and Stroop tasks were counterbalanced across participants. Ten participants were excluded because of technical problems with shock delivery. Two participants were excluded because less than 50% of trials were answered correctly. One participant had poor performance in the AX-CPT and the other in the Stroop task. They were dropped from both tasks so the samples were the same across task. (Aged 18-39, mean = 21.4, SD = 4.1. $N_{\text{Male}} = 9$, $N_{\text{Female}} = 52$. $N_{\text{White, not of Hispanic Origin}} = 42$, $N_{\text{Latino/Hispanic}} = 5$, $N_{\text{Middle Eastern}} = 4$, $N_{\text{African American/Black}} = 3$, $N_{\text{Asian/Pacific Islander}} = 3$, $N_{\text{American Indian/Alaskan Native}} = 1$, $N_{\text{Other}} = 1$.)

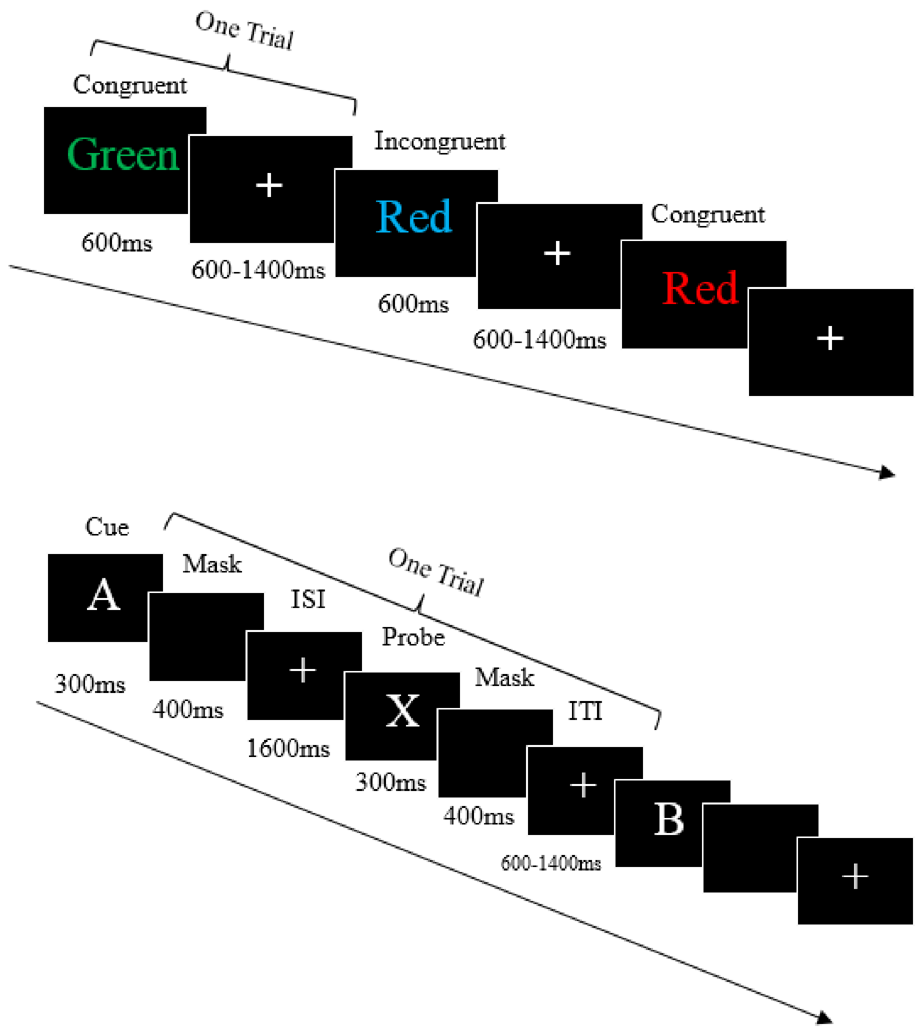


Figure 1. (a) Each trial started from a color word shown on the screen for 600ms, followed by a white fixation cross shown on the screen varying from 600-1400ms. The participants were asked to respond to the color of the words but not the meaning by pressing the same color button on the keyboard. There were two word conditions: Congruent and Incongruent. In congruent condition, the word reading and color naming were the same whereas the incongruent are not. (b) Each trial started when a white cue appeared on screen for 300ms then masked for 400ms. A fixation appeared on the screen for 1600ms, then the target was presented for 300ms, then masked for 400ms. The ITI varied from 600-1400ms, then the next trials started. Participants had 2100ms to respond.

Stroop Task Design and Procedures

This Stroop task was modified from the classic color-word Stroop task (Stroop, 1935). Each trial included a color word shown on the screen for 600ms, followed by a white fixation cross varying from 600-1400ms. The participants was asked to respond to the color of the text the word is displayed in but not the meaning of the word by pressing the same color button on the keyboard as accurately and quickly as possible. There were two word conditions: Congruent and Incongruent. In the congruent condition, the words ‘GREEN’, ‘RED’ and ‘BLUE’ were presented in their own color to maintain congruence of word reading and color naming. In the Incongruent condition, the word ‘GREEN’, ‘RED’ and ‘BLUE’ were presented in different colors from their meaning to cause interference. For example, when the word ‘GREEN’ was shown on the screen in the color red the participant should press the red button on the keyboard.

There were two trial conditions: safe and shock conditions. For the safe condition, there was a 30 pixel wide blue border around the edge of the screen and participants were explicitly told that they would not receive any shocks. For the shock conditions, the 30 pixel wide border would be red and participants were explicitly told that they might receive shock(s) on their ankle at any time. Before the test began, participants underwent a shock workup procedure to establish a level of shock that was ‘Painful but can tolerable’. The electrical shock was a constant current at this level delivered via an electrode placed on the outside of the participant’s right wrist for 500ms.

In each of six blocks, there were 35 congruent trials (70% of trials) and 15 incongruent trials (30%), with the trial order randomly assigned. There were three safe blocks and three threat of shock blocks (a total of 150 trials in each condition, shock and safe). Each safe block was followed by a shock block. During the shock block, participants might receive one, two or three electrical shock(s) on the wrist. After each block, participants rated their current anxiety level by pressing a button between 1 (low anxiety) and 7 (high anxiety).

AX-CPT Task Design and Procedures

The AX-CPT task consisted of continuous trials with a single letter presented on the computer, with each letter requiring a button press response from the participant. In each trial, a letter (cue) was displayed and followed by its paired letter (probe), which together comprised a Cue-Probe sequence. There were four Cue-Probe sequence trial types: AX, AY, BX and BY. The 'A' represented the target cue while 'B' represented the non-target cue, 'X' represented the target probe while the 'Y' represented the non-target probe. During the AX target trials, only the letters A and X were presented. However, in addition to A, B, X, and Y the non-target trials (AY, BX, and BY) also included the letters E, F, G, J, M, P, Q, R, S, U and V. The participants were instructed to response to each letter (cue and probe) by pressing button '1 (Yes, the target sequence completed) or '2' (No, the target sequence did not complete). That is, participants only pressed '1' when letter X (probe) was following the letter A (cue), which completed a target cue-probe sequence. Other than this, participants were instructed to press '2' to any cues and probe (e.g. B-X, A-G, M-Q). Each trial started when a white cue appeared on screen for 300ms then was masked for 400ms (see Figure 1(a)). After a fixation appeared on the screen for 1600ms, the target appeared on the screen for 300ms then was masked for 400ms. The ITI varied from 600-1400ms. Participants had 2100ms to make a response.

To manipulate proactive control, we attempted to instill a prepotent response to respond to the X (with a '1' button press) by presenting the AX target trial type more frequently (70% of trials) than the non-target trial types: 10% each for AY, BX, and BY. See Figure 1(b) for a depiction of the task design.

There were two trial conditions: safe and shock conditions. The shock procedure was the same as the Stroop test. The safe block had the 30 pixel wide blue border around the edge of the screen and 30 pixel wide red border for shock blocks. Participants were explicitly told whether they would receive any shocks or not before each block.

The whole AX-CPT task consisted of 10 blocks, with 5 safe and 5 shock blocks. Each safe block was followed by a shock block. In each block there were 40 trials, including 28 AX, 4 AY, 4 BX and 4 BY trials. All trial types were presented in a random order. During the five shock blocks participants received between 0 and 3 shocks (one block each of 0, 1, and 3 shocks, 2 blocks with 2 shocks). The order of these blocks was randomly assigned among shock blocks.

Before the experimental trials, participants conducted a practice block. Only when participants achieved 50% correct could they move on to the experimental trials. After each block, subjects were asked to rate their anxiety on a 7 point scale (1 = low, 7 = high).

Data Analysis

Stroop. 2.56% trials were excluded from analysis due to lack of response, 0.18% trials were excluded because the RT was less than 200ms, 1.91% trials were excluded because the shock occurred during this trial, and 0.76% trials were excluded because of RT longer than 3 standard deviations from the mean.

All accuracy and RT data were examined using a 2 (Condition: Safe vs. Threat) × 2 (Trial Type: Congruent vs. Incongruent) repeated measures ANOVA. A series of paired t-tests were used for the comparisons among conditions and trial types.

AX-CPT. The dependent variables will be accuracy and reaction time for responses to the probe letters. Only trials for which participants responded correctly to the cue will be analyzed. 2% trials were excluded from analysis because the shock occurred, 4.28% trials were excluded because of incorrect or no response to the cue. The median of the reaction time (RT) of each participant for each condition and trial type were used for the RT analysis.

AX-CPT accuracy and RT were examined using a 2 (Condition: Safe vs. Threat) × 4 (Trial Type: AX, AY, BX and BY) repeated measures analysis of variance (ANOVA). Paired t-tests were used for the comparisons among conditions and trial types.

In the repeated measure ANOVAs, if the Mauchly's test of sphericity assumption was violated, the Greenhouse-Geisser epsilon was used to correct the degrees of freedom.

Results

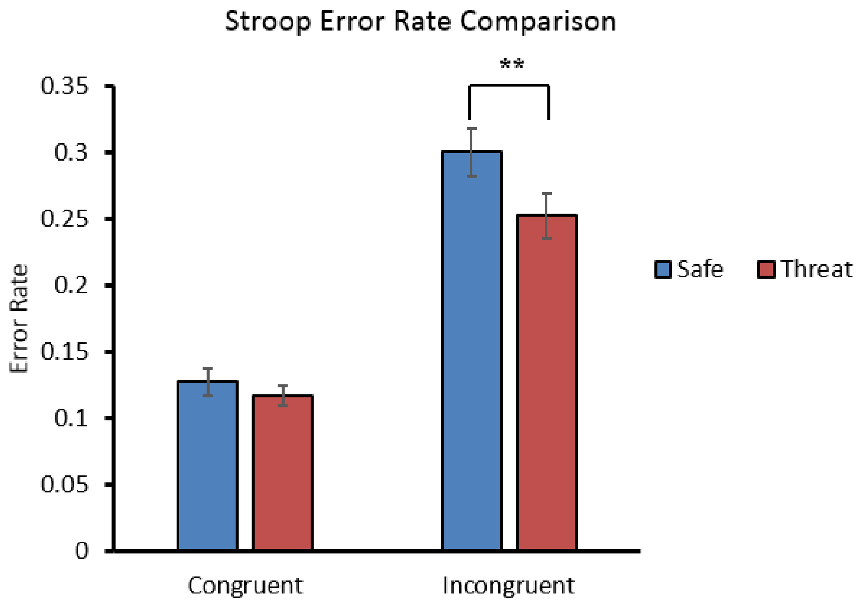
Stroop

The anxiety rating shows the shock did make participants felt significant more anxious $t(120) = 4.411$, $p < .001$, Cohen's $d = .399$.

Accuracy

A Condition (Safe, Threat) × Trial Type (Congruent, Incongruent) repeated measures ANOVA yielded significant interaction, $F(1,60) = 4.246$, $p = .044$, $\eta_p^2 = .007$, and main effects of Condition, $F(1,60) = 9.404$, $p = .003$, $\eta_p^2 = .135$, and Trial Type, $F(1,60) = 87.436$, $p < .001$, $\eta_p^2 = .593$ (See Figure 2(a)). The performance for incongruent trial type was poorer than congruent for both safe and threat conditions. However, as reflected by the interaction threat affected performance differently for congruent and incongruent trials. For incongruent trials, participants made fewer errors under threat of shock than during safety, $t(60) = 3.002$, $p = .004$, Cohen's $d = .388$. However, error rates did not differ between threat and safe for congruent trials, $t(60) = .980$, $p = .331$, Cohen's $d = .127$. This suggests that anxiety facilitated performance on the incongruent trials, in which reactive control is required to prevent engaging in the dominant word reading response.

(a)



(b)

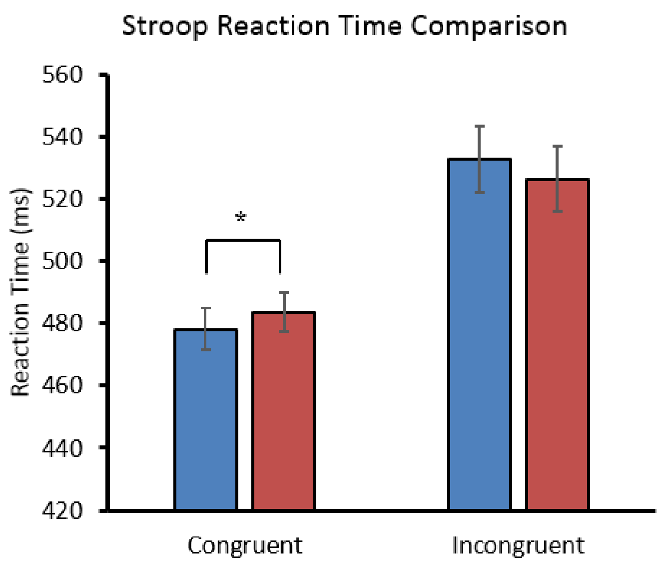


Figure 2. (a) Mean error rate for Stroop task for the safe and shock conditions for congruent and incongruent trials Error bars represent the standard error of the mean. (b) Mean reaction time for Stroop task for safe and shock conditions across trial types. Error bars represent the standard error of the mean. Asterisk represents significant RT difference. * $p < 0.05$; ** $p < 0.01$.

Reaction Time

The identical Condition × Trial Type ANOVA was conducted with RT as the dependent variable. This ANOVA yielded a significant interaction, $F(1,60) = 6.362$, $p = .014$, $\eta_p^2 = .096$, and main effect of Trial Type, $F(1,60) = 69.855$, $p < .001$, $\eta_p^2 = .538$ (See Figure 2(b)). As expected RTs were faster for the easier congruent trials compared to incongruent trials. Following up on the significant interaction revealed that RTs were slower for congruent trials during shock compared to safe conditions, $t(60) = 2.064$, $p = .043$, Cohen's $d = .267$.

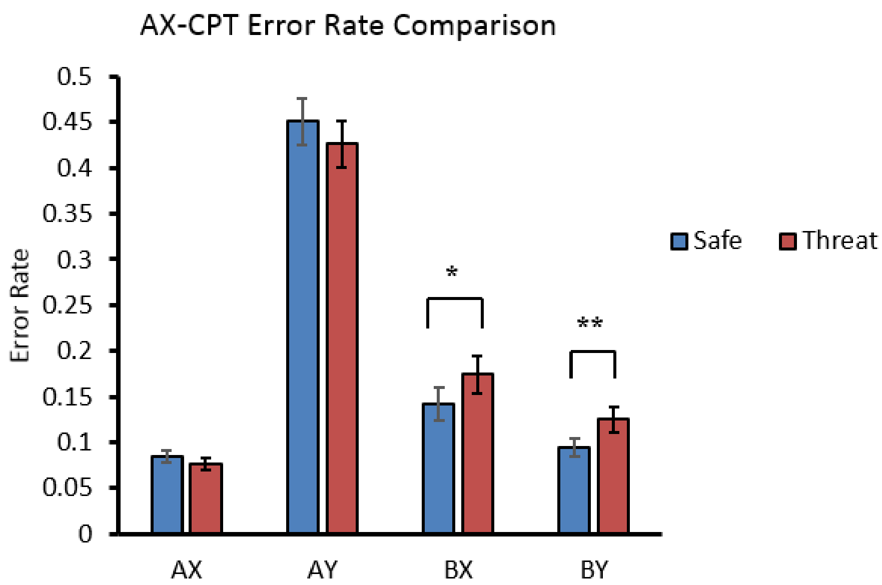
AX-CPT

The anxiety rating shows the shock did make participants felt significant more anxious $t(120) = 7.086$, $p < .001$, Cohen's $d = .642$.

Accuracy

A Condition (Safe, Threat) × Trial Type (AX, AY, BX and BY) repeated measures ANOVA yielded a significant interaction, F(2.469, 148.134 = 4.675, $p = .004$, $\eta_p^2 = .072$, and main effect of Trial Type, $F(1.803, 108.168) = 127.966$, $p < .001$, $\eta_p^2 = .681$, but no main effect of Condition (See Figure 3(a)). Post-hoc comparisons across threat and safe conditions (Bonferroni corrected) showed that the error rate for the AX trial type was significant lower than AY ($p < .001$), and BX ($p < .001$), but not BY ($p = .088$). Participants also made more errors during AY than BX ($p < .001$) and BY ($p < .001$) trials. The error rate for BX was also higher than BY ($p < .001$). Following up on the significant interaction, I found that the error rate was higher in the threat compared to safe condition for the BX, $t(60) = 2.109$, $p = .039$, Cohen's $d = .272$, and BY, $t(60) = 2.690$, $p = .009$, Cohen's $d = .347$, trial types. There was a trend for fewer errors under threat of shock in the AX condition, $t(60) = 1.906$, $p = .061$, Cohen's $d = .246$.

(a)



(b)

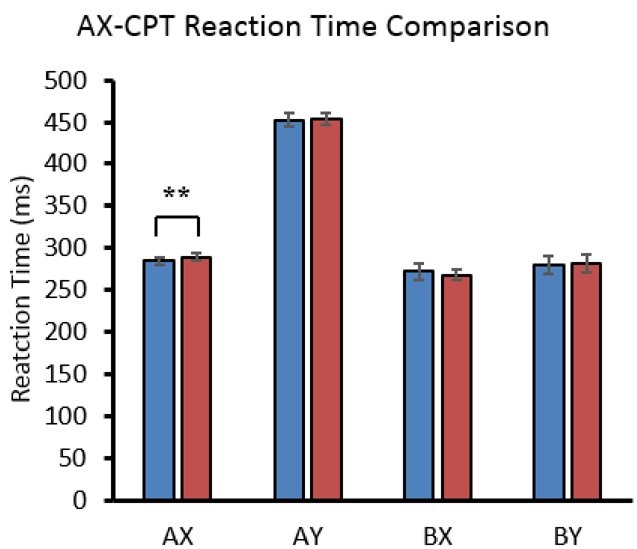


Figure 3. (a) Mean error rate for the AX-CPT task for safe and shock conditions across trial types. Error bars represent the standard error of the mean. (b) Mean reaction time for the AX-CPT task for safe and shock conditions across trial types. Error bars represent the standard error of the mean. Asterisk represents significant RT differences. * $p < 0.05$; ** $p < 0.01$.

Reaction Time

A Condition (Safe, Threat) × Trial Type (AX, AY, BX and BY) ANOVA was calculated with RT as the dependent variable. There was a significant main effect of Trial Type, $F(2.085, 123.007) = 499.809$, $p < .001$, $\eta_p^2 = .894$, but no main effect for Condition, $F(1, 59) = .530$, $p = .470$, $\eta_p^2 = .009$, or Condition × Trial Type interaction, $F(2.085, 123.007) = 499.809$, $p = .933$, $\eta_p^2 = .002$ (See Figure 3(b)). Post-hoc comparisons across threat and safe conditions (Bonferroni corrected) showed that RT for the AX trial type was faster than AY ($p < .001$), slower than BX ($p = .004$), and did not differ from BY ($p = .090$). RT for AY was also slower than BX ($p < .001$) and BY ($p < .001$). RT during BX was not significant faster than BY ($p = .602$). Despite the lack of interaction we did conduct post-hoc comparisons to test our a priori hypotheses. There was no significant difference between threat and safe during the AY, BX, or BY conditions, $F(1, 59) = 0.530$, $p = .470$, $\eta_p^2 = .002$. We did find that RT was significantly slower during threat than safe for AX trials, $t(60) = 3.336$, $p = .001$, Cohen's $d = .431$].

Discussion

Our study's purpose was to assess how state anxiety impacts two distinct forms of cognitive control. The current results support our hypothesis that state anxiety impairs proactive control but enhances reactive control.

The Stroop task served as our index of reactive control. In the Stroop task, contextual information or trial-by-trial maintenance of a goal is not required to make a response, but simply a reaction to the current stimulus. Together the dominant tendency to read the word and the high frequency of congruent trials in our design biased participants to respond relying more on wording reading, which is more automatic than color naming. Thus, word reading is the prepotent response and in order to respond correctly on incongruent trials individuals react quickly to engage control mechanisms to avoid word reading resulting in an incorrect response (Botvinick et al., 2001). Evidence shows that color naming on incongruent trials in the Stroop task reflects reactive control, particularly when the majority of trials are congruent (Botvinick et al., 2001; Gonthier et al., 2016; Lesh et al., 2013). Our results are consistent with previous findings that the error rate for the incongruent condition (collapsed across safe and shock conditions) was higher than congruent condition (Botvinick et al., 2001; MacLeod, 1991). It has been suggested this incongruence causes conflict which requires the conflict monitoring system to be triggered and attention is deployed to modify behavior to meet this task goal. Reactive control is related to this conflict monitoring system and enhancement of this system facilitates reactive control performance (Egner & Hirsch, 2005; Kerns et al., 2005). Activation of the ACC, a region implicated in conflict monitoring and cognitive control, has been shown to be higher when frequency of incongruent trials was lower (C. S. Carter et al., 2000).

Considering the effects of state anxiety, as we hypothesized, we found that fewer errors were made on incongruent trials in the shock condition compared to safe. That is, under threat of shock, the task-irrelevant process (word reading) was inhibited and the task-relevant process (ink color naming) was enhanced, and as a result fewer incorrect responses were made. When the color naming is incongruent with word reading, two incompatible response tendencies are activated (word reading, color naming) and the conflict monitoring system is engaged to inhibit the prepotent word reading response. Our findings indicate that state anxiety enhances inhibition of word reading to modify behavior to avoid making an incorrect response. This result is consistent with a similar Stroop test in which shock threat slowed responding during neutral Stroop trials but facilitated responding on incongruent trials (Hu et al., 2012). This facilitation could be interpreted in keeping with the attention narrowing hypothesis that anxiety decreases the processing of task irrelevant dimensions (Callaway, 1959; Callaway & Dembo, 1958; Chajut & Algom, 2003; Eysenck & Calvo, 1992; Eysenck et al., 2007).

As noted above, the inhibition necessary for incongruent Stroop trials requires reactive control, thus our findings support our hypothesis that state anxiety would improve reactive control. This is consistent with previous findings. N2 amplitudes, which are generated by the ACC and associated with enhanced attentional performance, have been found to be greater to incongruent versus congruent flankers prior to a correct response suggesting greater involvement of ACC in conflict monitoring and successfully overcoming response conflict (Schmid, Kleiman, & Amodio, 2015). Another study found only the N2 amplitudes of congruent but not incongruent flankers significantly increased when anxiety increased (Dennis & Chen, 2009; Yeung, Holroyd, & Cohen, 2005). The authors suggest that under higher anxiety the N2 is enhanced in low conflict condition and the reduced N2 difference may reflect a compensatory mechanism to minimize potential attentional interference in the face of threat. These findings suggest that threat may facilitate reactive control by enhancing the activity of ACC. The ACC is a critical node in the conflict monitoring system, which responsible for the overriding prepotent responses, (Botvinick, Cohen, & Carter, 2004). fMRI studies have shown that during high conflict correct responses, the ACC is responsible for conflict monitoring including error detection and behavioral correction, and it is the only area that shows greater activation when behavior is subsequently adjusted after conflict is detected. (Cameron S. Carter et al., 1998; Garavan, Ross, Murphy, Roche, & Stein, 2002). Therefore, the anxiety enhance the reactive control by facilitating the conflict monitoring system of ACC.

If state anxiety enhances reactive control, then it might be expected that RT for the incongruent trial type may also be facilitated, along with accuracy. However, no significant RT difference was found for incongruent trials between safe and threat. This suggests that state anxiety facilitated accurate performance and that this did not come at the expense of a longer response time.

Turning to proactive control, our AX-CPT task findings indicate that regardless of threat condition both BX and AY trial types, which required more context-based responding (i.e., maintenance of the cue-probe relationship), resulted in more errors than AX and BY trial types. This result is consistent with other findings (D. M. Barch, Carter, MacDonald, Braver, & Cohen, 2003; Cohen et al., 1999b; Lopez-Garcia et al., 2016; MacDonald Iii et al., 2005). In addition, the error rate for AY trials was significantly higher than the other three trial types and no significant difference was found between safe and threat condition. Thus, as is intended the high frequency of the AX trials established a prepotent response tendency, which impaired accuracy on AY and BX trials as participants were biased to respond incorrectly. For these conditions more effort was required to maintain and update the task goal and inhibit the prepotent response and prevent a false alarm response. Overall, the pattern of findings across the four trial types is largely consistent with previous work (D. M. Barch et al., 2001; Cohen et al., 1999b; Lopez-Garcia et al., 2016).

As we hypothesized, the introduction of state anxiety resulted in more errors on trials demanding more proactive control, in this case both BX and BY trials. For BX trials, the occurrence of probe X biased participants to respond as though it were a target (AX) trial. To properly respond in the BX condition, the contextual information provided by the cue B should be used in an inhibitory fashion to override the tendency to false alarm in response to the probe X (Braver et al., 2001). Braver and his colleagues (2001) claimed that both attention and inhibitory functions in the AX-CPT test are subserved by an internal representation of context information within DLPFC. This context-necessitated inhibition requires proactive control in the BX trial type.

Anxiety is thought to impair processing efficiency by restricting the capacity of working memory (Darke, 1988) and increasing the allocation of attention resources to threat-related stimuli internally and externally, thus impairing performance (Sarason, 1988). Following this logic, we expected performance on BX trials to be impaired under anxiety as they require more attention and maintenance to prevent a false alarm response to the "X". Indeed we found the error rate for BX was higher in the threat than safe condition. This finding is consistent with the hypothesis that anxiety impairs proactive control. Specifically, anxiety impaired the override of the prepotent response to the probe X, which requires maintenance of the contextual information provided by the B cue during the delay. Because working memory function is assumed to be involved in tasks of delayed contingent response (Braver et al., 2001), it is suggested that state anxiety occupied more working memory resources and impaired the goal-driven system by insufficiently maintaining task-related information, which caused more errors.

In addition to threat's impact on BX trials we also somewhat unexpectedly found that threat similarly impacted BY performance, such that more errors were made in threat compared to safe condition. This may be caused by the need for more attention and utilization of working memory allocated to the infrequent non-target cue B. In contrast to the easier AX trials, the BY trials required more proactive control, and thus were also affected by threat of shock like the BX trials.

The RT results show that the AY trial type required more time than other types to respond, which is consistent with other findings (D. M. Barch et al., 2003; Deanna M. Barch et al., 2004; Braver et al., 2001; Lopez-Garcia et al., 2016). AY responses are thought to be slowed because the anticipated target response to an "X" needs to be inhibited which requires additional time. The RT for BX trial type was faster than AX and AY, but not BY. Similar results were also found in other studies (D. M. Barch et al., 2003; Deanna M. Barch et al., 2004). It suggests the non-target cue B can facilitate the response speed. However, no significant RT difference was found between safe and threat for AY and BX trial types.

Interestingly, the only significant RT difference between shock and safe conditions was found for the AX trial type, with RT being slower under state anxiety. This is similar to the RT performance for the congruent trial type in the Stroop test. In both cases these trials were presented with high frequency (70%) establishing a more automatic prepotent response. Across tasks we find that state anxiety compromised speed in performing these simplest task conditions. It suggests that state anxiety may slow down response speed by relocating attention to potential threat.

Attentional Control Theory (Eysenck et al., 2007) claims the anxiety impairs efficient functioning of the goal directed attentional system and enhances processing by the stimulus-driven attentional system. Thus, attentional control is decreased, but attention to threat-related stimuli is enhanced. Inhibition and shifting are the two central executive functions supporting processing efficiency that are adversely affected by anxiety (Eysenck et al., 2007). Studies have found that when task demands on working memory capacity are high, the adverse effects of distractors on task performance increased (Graydon & Eysenck, 1989). Individuals with lower working memory capacity are more susceptible to distractors (Barrett, Tugade, & Engle, 2004). In a selective attention task, the same adverse effects of distractors was found and it was greater when these distractors were involved with shifting function (Lavie, Hirst, de Fockert, & Viding, 2004). Attentional Control Theory suggests the anxiety occupies the limited working memory capacity with threat-related information, both task-relevant and irrelevant. They posit that this leads to low central executive performance, but high performance on conflict monitoring. In other words, anxiety may unitize more working memory resources on relocation of attention to task-unrelated stimuli, which serves to enhance reactive control but impair proactive control.

In keeping with this, we found that state anxiety differentially impacted reactive and proactive cognitive control during Stroop and AX-CPT test. State anxiety enhanced accuracy on incongruent Stroop trials, which require reactive control, but impaired performance on BX and BY trials in the AX-CPT, which depend on proactive control. As would follow from the effects of anxiety on attention and working memory described above, we posit that state anxiety enhanced attention to threat, in this case via the conflict monitoring system, to quickly modify behavior on the incongruent Stroop trials. In contrast, state anxiety impaired goal maintenance on the AY, BX and BY trials by occupying limited working memory capacity, leading to impaired context processing. This is consistent with a recent study that found that low anxiety subjects were engaged with proactive control driven by DLPFC and high anxiety subjects were engaged with reactive control by conflicted related dorsal ACC (Schmid et al., 2015). The distinction between proactive and reactive control in the DMC theory is supported by this differential task performance under threat.

A limitation of this task is that the inter-stimulus interval for the AX-CPT was quite short. A longer duration would require more working memory resources to maintain the cue information, which is highly relied on for proactive control. Even though we found a difference in error rate for BX trials, no speed difference was found. If the inter-stimulus interval was longer, thus increasing the difficulty of goal maintenance, RT may also have been impaired on proactive control trials, such as the BX.

Conclusion

We found that state anxiety differentially impacted proactive and reactive cognitive control. State anxiety enhanced reactive control, potentially by facilitating the conflict monitoring system, enabling modification of behaviors according to environmental changes. Enhanced reactive control under threat may have adaptive functions in altering ongoing behavior to respond appropriately to potential threats. In contrast, state anxiety impaired performance in situations requiring proactive control. Additional goal maintenance demands in these proactive control-demanding tasks likely impinges on limited working memory capacity. The processing of task irrelevant information, particularly potential threat, interferes with execution of ongoing task goals, and impairs performance. The interesting additional finding of state anxiety slowing of responses in simple task conditions also supports the idea that potential threat occupies limited resources and impacts task performance. In sum, state anxiety differentially impacts reactive and proactive control, in ways that reflect adaptive responding to potential threats in the environment and that disadvantage performance in more complex conditions that require maintenance of contextual information to facilitate performance.

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CURRICULUM VITAE

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EDUCATION

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EXPERIENCE

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- Led a team of 10 research assistants to complete two human and computer interaction based emotion and cognitive control tasks, using Qualtrics to design, survey and collect data, analyzed using SPSS.
- Directed a team to completion of an eye-tracking and visual cognition experiment, six months ahead of expected deadline.
- Teach undergraduate courses 'Psychology Statistics' 'Research Methods'; Online courses; Eye-Tracking method and SPSS.
- Grade, analyze and track students' performance in each semester while providing feedback and strategies to students at different levels.
- Analyzed behavior and eye movement when they were reading web page experience based on over 100 participants.
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Senior Teacher
Zhuhai Experimental High School - Zhuhai, CN **August 2006 to June 2010**

- Taught biology courses for four years, including a course that tested as the most difficult on Chinese college entrance exam.
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RESEARCH AND PUBLICATION

- Zhao, N., Zhang, X., Yang, Y., Song, C., He, B. & Xu, B.(2018). The effects of treadmill exercise on autophagy in hippocampus of APP/PS1 Transgenic mice. (NeuroReport, SCI, In Press.)
- Yang, Y., Miskovich, T. & Larson, C.L. (2018). State Anxiety Impairs Proactive But Enhances Reactive Control. (Ready to be published in Emotion. SSCI.)

- Yang, Y., Hanson, R., Coutinho, M.V.C., Greene, A.J., & Hannula, D.E.(2018). Contextual Cueing is Inflexible and Best Characterized as Associative Rather than Relational Learning. (Ready to be published in Journal of Experimental Psychology. SSCI.)
- Yang, Y., Miskovich, T. & Larson, C.L. (2017). How does anxiety affect cognitive control? Proactive and reactive control under state anxiety. Poster session presented at Wisconsin Symposium on Emotion. Madison, WI
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    - Sigma Xi Member, 2013-2014

AWARDS

- Distinguished Teaching Award, 2007, 2008, 2009, Zhuhai Experimental High School
- Excellent Young Teacher, 2007, 2008, 2009, Zhuhai Experimental High School
- Distinguished Instructor Award of Zhuhai Youth Science & Technology Innovation Competition, 2009 Zhuhai City
- Teaching Assistantship, 2010,2011,2012,2013,2014,2015,2016
  University of Wisconsin Milwaukee
- UWM Travel Award, 2012, 2014 University of Wisconsin Milwaukee

SKILLS

Trilingual: | Mandarin | Cantonese | English |

Technical: | UX research | Data Analysis | Excel | SPSS | Userability Hub | Userzoom | Qualtrics | Eye-tracking | HTML | User Experience Design | User Interface Design | Google Analytics | Illustrator | E-Prime | Axure RP | Sketch | Optimizely | A/B Test | Microsoft Office | Photoshop | Premiere