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Proactive and Reactive Cognitive Control Under Threat of Unpredictable Shock: A Combined Eye-Tracking and EEG Study Using Multilevel Modeling

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PROACTIVE AND REACTIVE COGNITIVE CONTROL UNDER THREAT OF UNPREDICTABLE SHOCK: A COMBINED EYE-TRACKING AND EEG STUDY USING MULTILEVEL MODELING

by

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ABSTRACT

PROACTIVE AND REACTIVE COGNITIVE CONTROL UNDER THREAT OF UNPREDICTABLE SHOCK: A COMBINED EYE-TRACKING AND EEG STUDY USING MULTILEVEL MODELING
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Under the Supervision of Associate Professor Han-Joo Lee, Ph.D.

We are constantly bombarded by environmental distractors in daily life which interfere with internal, ongoing goals, thus cognitive control processes need to be in place to adapt to maintain these goals in light of the environmental demands. These cognitive processes (generally referred to cognitive control) are thought to be adjusted reactively or proactively to deal with distractors. There is little evidence on how state anxiety dynamically interacts with these two modes of cognitive control. Taking advantage of a multimodal methodology, through two experiments, we replicated existing findings of reactive and proactive control processes via utilizing a Flanker task in a laboratory setting, and acquired evidence of neurocognitive (N2, 200-350ms, and frontal slow-wave, 500-700ms, components) and eye-gaze (dwell-time) indices corresponding to these modes using a highly stringent, multilevel modeling approach. In the second experiment, we administered the threat of unpredictable shock and demonstrated that induced state anxiety, versus safe, had an overall enhancing effect on reaction time (RT) but no effect on accuracy, regardless of the mode of cognitive control. However, shock had a unique enhancing effects on reactive control by shifting its mode of operation from “reactiveness” toward “preemptiveness” while having a dampening effect on the proactive mode through using attentional resources and leaving limited capacity for proactivness in the face of highly frequent distractors. Unlike previous studies, we found a potentiation of N2 amplitude and longer eye-

gaze fixations for proactive mode to further support the idea that the proactive mode might be associated with some compensatory activity under the threat of shock which might result in a better overall performance compared to reactive mode, however, this compensation could not outperform the proactive mode under the safe condition. Overall, the multilevel modeling along with the multimodal methodology adopted in this experiment provided strong supportive evidence of previous experiments in the context of induced state anxiety and suggested a replication of this finding with individuals with trait anxiety to further disentangle the differences observed in cognitive control between induced state anxiety and trait anxiety.

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1. Introduction

1.1. Proactive and reactive cognitive control

In daily life activities, we are constantly exposed to a wide range of environmental stimuli and distractors. This necessitates adaptive cognitive processes to gate in relevant information for internally maintained behavioral goals and filter out irrelevant, yet disturbing effects of distractors to the task at hand. These cognitive processes, collectively referred to as cognitive control, ensure regulating and maintaining current representations of internal goals in the presence of salient background distractors while simultaneously and strategically updating these internal representations based on environmental demands (Braver, 2012; Braver et al., 2009).

One significant aspect of goal-driven decisions is how cognitive control uses attentional resources to enhance processing of target stimuli and suppress irrelevant distractors. The Dual Mechanism of Control theory (DMC; Braver, 2012; Chiew & Braver, 2017) has recently received much attention for its dichotomous framework to account for operationalization of cognitive control in various distraction suppression scenarios and posits two distinct modes of cognitive control: *proactive distraction filtering (PDF)* and *reactive distraction filtering (RDF)* (Braver et al., 2008). RDF relies on adjustments of attentional control *in response to* distractors or conflict and is assumed to be the “default mode” of cognitive control due to its resource efficient mechanism (Marini et al., 2013). On the other hand, PDF is an effortful, sustained attentional deployment that *pre-emptively* enhances selective target processing prior to distracting inputs (Appelbaum et al., 2012; Bugg & Crump, 2012; Mäki-Marttunen et al., 2019).

Several studies have investigated specific behavioral characteristics of RDF and PDF (Blais et al., 2007; Bugg, 2008; Bugg & Crump, 2012). In a series of experiments, Marini et al.

(2013) used an attentional control design called the "distraction-context manipulation paradigm" to manipulate and examine the effectiveness of RDF and PDF across different sensory modalities (e.g., auditory, visual, tactile) and to investigate whether recruitment of these control modes is associated with any behavioral costs. Distraction-context manipulation paradigm is based on the premise that mere exposure to frequent distracting and high-conflicting stimuli instigates the PDF mechanism to pre-emptively reduce the taxing effect of goal-irrelevant distractors (Marini et al., 2013, 2016). However, the PDF activation might actually render behavioral cost when expected distractors are absent (Marini et al., 2013). The authors reported that varying blocks of this paradigm (e.g., mostly congruent [=RDF], mostly incongruent [=PDF]) produced two distinct behavioral costs: *conflict and filtering costs*. *Conflict cost* is defined as a contrast between reaction times (RTs) of incongruent and congruent trials within each block. A lower level of conflict cost was observed for the block with mostly incongruent trials, which may be due to the operation of PDF. *Filtering cost* is defined as a contrast of RTs on trials with no distractors (single arrow) embedded within potentially distracting vs. non-distracting contexts (e.g., PDF - Pure blocks). The significance of this study was the negative association observed between conflict and filtering costs, supporting their hypothesis that activation of PDF could render reduced congruency interference (= lower conflict cost) in a potentially conflicting context due to preemptive distraction filtering. However, this activation may tax the brain on trials where expected distractor stimuli are absent, hence producing a larger filtering cost (Marini et al., 2013, 2016).

Although Marini et al.'s work provided behavioral evidence of effectiveness of RDF and PDF to deal with a potentially distracting context, it lacks corresponding evidence on neural signature with a high temporal resolution or specific attention allocation characteristics via eye-gaze. To address this gap of knowledge, we conducted a preliminary study to manipulate and examine the effectiveness of RDF and PDF and obtained behavioral, eye-gaze and event related potentials (ERP) characteristics. The study utilized a Flanker task (see Fig. 1; Eriksen & Eriksen, 1974) with three blocks to create different levels of expectations for conflicting information: "Pure" block (presenting only the central arrow without flanking distractors), "Reactive Distraction Filtering" (RDF block; 60% congruent, 20% incongruent, and 20% distractor-absent [Dist-Abs] trials, designed to trigger RDF), and "Proactive Distraction Filtering" (PDF block; 60% incongruent, 20% congruent, and 20% Dist-Abs trials; designed to trigger PDF). As mentioned earlier, the task indexes conflict-cost (i.e., incongruent RT – congruent RT) and filtering-cost (i.e., Dist-Abs RT in PDF or RDF – Dist-Abs RT in Pure). Our behavioral data replicated Marini et al.'s results (2013) and showed that PDF significantly lowered the conflict-cost while increasing the filtering-cost, indicating that although PDF is beneficial when distraction presents, its recruitment is not without costs when expected distraction is absent. The overall accuracy of PDF was also significantly larger than RDF, which supports the idea that proactive control enhances efficiency of distraction suppression. Eye-tracking data revealed that compared to RDF, PDF is characterized by prolonged fixations on the central target with reduced attention deployed toward the peripheral area, suggesting that the heightened filtering-cost in PDF may be associated with the narrow attentional focus with inflexible or deficient attentional deployment toward the peripheral areas surrounding the central target.

In ERP literature related to conflict provoking tasks (e.g., Flanker, Stroop, Simon), N2 (Larson et al., 2014), N450 (Appelbaum et al., 2014), and MFN (Medial Frontal Negativity; West et al., 2012) are all referred to as the same family of negative going components appearing around 200-500ms post-stimulus at frontocentral EEG electrodes that are believed to be generated from the brain structures reside in anterior cingulate cortex (ACC) and signal the detection of conflict between competing stimuli or response representations. The frontal slow-wave (FSW; Von Gunten et al., 2018), late positive potential (Appelbaum et al., 2014) or conflict-related slow potential (Larson et al., 2014) observed in Flanker and Stroop tasks are also slow wave components occurring very late (after 600ms post-stimulus) at fronto-central electrodes shown to closely reflect cognitive control effort during response selection or conflict resolution during response selection. Using a pair of dipoles, West et al. (2012) suggested that the middle and inferior frontal gyrus (i.e., where dlPFC resides) might be the likely places to generate FWS. The multilevel modeling of ERP data in our pilot study demonstrated that N2 amplitude was more negative in RDF (larger magnitude) compared with PDF, showing that PDF operates pre-emptively in anticipation of forthcoming distractors resulting in an overall lower level of conflict. FSW was more positive for Dist-Abs trials in PDF compared to RDF blocks (i.e., a neural evidence of larger response generation effort associated with PDF). This result suggested N2 overall might trigger a cognitive monitoring signal driven from ACC (Botvinick et al., 2001) to up-regulate attentional focus on next trials, while FSW was reflective of the magnitude of implemented cognitive control resources to generate a response when there was a mismatch in the anticipated stimuli set (i.e., the absence of anticipated distractors; Clayson & Larson, 2011; Larson & Clayson, 2014). The excessive RT filtering cost in PDF block and its associated larger FSW is in line with previous reports (Czigler et al., 2006; Escera & Corral, 2007; Pazo-Alvarez et al., 2003) indicating that preemptive, effortful characteristics of PDF creates expectations of stimulus attributes for distracting stimuli (e.g., adopting a strategic distraction suppression mechanism at lower level visual cortex to preventively suppress distractors (Marini et al., 2013, 2016). When there is absence of the anticipated distracter, it may render the generation of proper response more laborious due to the violation/mismatch in expectancy. Thus, the operation of PDF appears to be beneficial in reducing the level of conflict stemming from incongruent trials, which is well aligned with the expectancy. However, the preemptive attentional regulation by PDF may actually turn out to be counterproductive when the expectancy is violated by the absence of distracters. In contrast, RDF does not induce such preemptive regulatory processes, and would be more efficient in processing the distraction-free trials by relying on the default, reactive, and more stimulus-driven process. Overall, the first study was able to experimentally create reactive and proactive control processes in a laboratory setting utilizing a single cognitive task, examine them, and provide behavioral, eye-gaze, and neural correlates of their underlying characteristics by using a highly stringent methodology.

In sum, PDF is an effortful, sustained attentional deployment that pre-emptively enhances selective target processing prior to distracting inputs, thus resulting in lower RT conflict cost and lower magnitude of N2 for distracting trials, but higher RT filtering cost and larger FSW amplitude for trials without distractors. In contrast, RDF involves the late adjustment of attentional control in response to infrequent distractors or conflict, thus resulting in higher RT conflict cost and larger magnitude of negative-going N2 for distracting trials, but no elevation in the behavioral filtering cost or FSW amplitude.

1.2. Anxiety and cognitive control

The effect of fear and anxiety on cognitive functioning has been well-documented (Bishop, 2007; Eysenck et al., 2007; Pessoa, 2009); however, there is still insufficient evidence about the effects of anxiety on proactive and reactive modes of cognitive control. Anxiety/fear can disturb or enhance distraction control, depending on current task difficulty, the extent to which the anxiety is provoked, or different modes of anxiety (i.e., trait or state; Robinson et al., 2020; Grillon et al., 2020). A growing body of evidence has suggested attentional bias towards processing of threat in anxiety disorders (Bar-Haim et al., 2007; Lee & Telch, 2008), state anxiety (Quigley et al., 2012), and dispositional anxiety (Stout et al., 2015, 2017). The attention control theory, as one of the prominent theories that predicts this effect, posits that processing efficiency of attention control is disrupted via anxiety by virtue of impairing three specific functions of cognitive processes (i.e., inhibition, updating, and shifting; Eysenck et al., 2007). The dual competition framework (Pessoa, 2009) posits that the interaction of emotion and cognition takes place in the form of competitions of task-irrelevant threat information for central processing resources of cognitive function. This theory predicts that threat-related information will more severely interrupt tasks with attentional conflict or interference characteristics compared to tasks with reliance on more habitual responses. These theories are constructed based on studies which mostly used dispositional and clinical anxiety samples to examine interrupting effect of anxiety on cognitive control, instead of investigating an imminent the threat of shock effect (Robinson, Vytal et al., 2013). Studies that implemented the threat of shock for assessing its effect on attentional control have reported enhancing effect and reduced stimulus-response conflict (Hu et al., 2012; Robinson, Vytal, et al., 2013). Moreover, converging evidence from the effect of the threat of shock on sensory gating support the notation that state anxiety has enhancing effect on general perceptual processing by lowering the threshold for detecting extrinsically and intrinsically salient stimuli, although it might overload the sensory system (Baas, Milstein, Donlevy, & Grillon, 2006; Cornwell et al., 2007, Robinson et al., 2013). This enhanced early sensory processing was nicely shown in Baas et al.’s study (2006) where increased brainstem signal activities in response to the threat of shock resulted in a better auditory processing, suggesting this enhanced sensory registrations may precedes cortical processing. Other evidence also suggested that the threat of shock facilitated inhibition from prepotent response to *noGo* targets by significantly reducing commission errors while leaving RT intact across both Go and noGo trials (Robinson et al., 2013). In a follow-up fMRI study, this group (Torrisi et al., 2016) replicated the behavioral result of Robinson et al. (2013) and showed greater activation of a right-lateralized frontoparietal network previously implicated in sustained attention and response inhibition. Additionally, overwhelming evidence from studies using shock threat and conflict-inducing tasks such as Stroop suggested an enhancing effect of shock on reduction of stimulus-response conflict effect. Although few studied have reported larger interference effect in presence of the threat of shock (Choi et al., 2012), most studies reported improved performance on the Stroop interference effect with a lower RT and accuracy for incongruent trials of shock versus the safe condition (Hu et al., 2012; Robinson, Vytal, et al., 2013; Yang, Miskovich, Larson 2018). Combining the threat of shock paradigm with a modified Stroop task, Yang et al. (2018) lowered the frequency of incongruent trials to 30% (congruent = 70%) to provoke a larger conflict effect and to increase a greater reliance on reactive control. Consistently, they reported a lower accuracy and faster RT in shock relative to the safe condition in response to incongruent trials, suggesting an enhancing effect of shock on reactive cognitive control (Yang et al., 2018).

This improvement of conflict reduction has been also reported in other studies using physical or mental methods of provoking anxiety (e.g., loud noises, time pressure or threat to ego) in conflict or Stroop tasks (Booth & Sharma, 2009; Chajut & Algom, 2003). These results seem to be in line with Easterbrook’s proposal (1959) in that high state of anxiety selectively narrows the focus of attention to a center location to process the target and suppress distracting peripheral cues (Easterbrook, 1959).

1.3. Neural correlates of the effect of anxiety on cognitive control

Only a few studies aimed to investigate neural signatures of interaction of reactive and proactive mechanisms with anxiety using high trait anxious samples or the threat of shock. Schmid et al., (2015) showed high socially anxious individuals relied more on reactive control relative to low socially anxious individuals which was putatively driven by higher activity of dorsal ACC (dACC), indexed by a greater N2 like ERP component (Schmid et al., 2015). Conversely, low social anxiety participants showed greater proactive control, driven by dorsal lateral prefrontal cortex (dlPFC; indexed by greater left frontal alpha asymmetry; Schmid et al., 2015). Investigating only the behavioral evidence, Yang et al. (2018) also showed that state anxiety impaired proactive control using an AX-CPT task. It is possible that the threat of shock might particularly enhance monitoring performance enabled by dACC and disturb goal maintenance supported by dlPFC structures (Yang et al., 2018). In fact, numerous studies have shown implication of dlPFC in emotional regulation (Grillon et al., 2019; Robinson et al., 2019) as well as its hyporactivation in anxiety disorders when performing cognitive tasks.

In our pilot experiment, we used the N2 ERP component as an index of conflict monitoring and reactive control. We also used the FSW as an indirect index of effortful response generation. Studies have showed that the middle and inferior frontal gyrus (i.e., where dlPFC resides) are putative generators of FSW component. It appears that N2 obtained from the Flanker task has been less investigated in ERP studies of anxiety compared to other components (e.g., ERN; Larson et al., 2014). In a study with individuals with generalized anxiety disorders (GAD), Larson et al. (2013) reported comparable conflict adaptation accuracy and intact RT for this populations relative to a healthy control. However, the GAD group demonstrated impaired neural signature of conflict adaptation indexed by N2 amplitude, indicating this reduced N2 might have been affected by some cognitive compensatory mechanism at the expense of a better accuracy and RT.

Taken together, most of the studies pertaining the behavioral and neurophysiological accept of cognitive control and anxiety have involved either clinical anxiety or dispositional/trait anxiety, and to our knowledge, there is no neurophysiological evidence of examining RDF and PDF of cognitive control under the threat of shock. Using this translational method of the threat of shock to manipulate state anxiety effect on RDF and PDF, we can provide more distinct behavioral and neural signatures evidence on this interplay and try to enrich the literature using a carefully controlled experimental model.

1.4. Anxiety, cognitive control, and eye-gaze information

There are little empirical data pertaining to how one's attention engages in and disengages from target stimuli under the PDF and RDF context, specifically in anxious state (Weaver et al., 2017). Some studies argued that PDF may prioritize target features and/or actively suppress the anticipated distractor features (Geng, 2014). Other studies have shown that active suppression of distraction as in the case of PDF always follows the initial attention to distraction and may not be preemptively suppressed (Moher & Egeth, 2012). Static or dynamic aggregations of eye-gaze durations and fixations would reveal distribution of overt attentional focus across target and distractor and help to closely examine the role of PDF and RDF. Many of past reports involving attention, eye-tracking and anxiety examined attentional bias for threatening stimuli. Using a low to high trait anxiety sample combined with a threat induction condition to provoke state anxiety, Quigley et al. (2012) reported that state anxiety resulted in a longer duration of eyes initial gaze and fixation on threating images compared to neutral, regardless of participants' level of trait anxiety, suggesting that state anxiety is associated with attentional bias to threat. In a systematic meta-analysis review of eye-tracking and attention to threat in children and adolescent anxiety, Lisk et al. (2020) reported youths with anxiety had significantly lower overall dwell time on threat versus neutral stimuli compared to control groups. This result is inconsistent with an earlier meta-analysis review concluding that anxious adults relative to non-anxious spent greater free viewing time and initial vigilance for threat stimuli (Armstrong & Olatunji, 2012). Most of these studies, however, did not directly measure eye-gaze characteristics of attentional control under an imminent threating condition and used tasks with emotionally salient stimuli (e.g., emotional Stroop task; Armstrong & Olatunji, 2012; Cisler & Koster, 2010; Lisk et al., 2020). Relatively, the interaction of state anxiety with the eye-gaze properties for PDF and RDF has not been reported before. Therefore, in the current study, we intended to replicate the findings of our pilot study under the safe condition and extended this literature by testing the effect of the threat of shock on RDF and PDF cognitive control while utilizing high temporal-resolution EEG methodology along with eye-tracking recording. We believed this study can shed light on corresponding brain mechanisms supporting the implementation of these cognitive control abilities in high temporal (ERP) and spatial (gaze) dynamics under state anxiety. Therefore, this study sought to investigate the following hypotheses:

1.5. Aims and hypotheses

(1) Aim 1. *To examine whether the results of the pilot study can be replicated under the safe condition in terms of behavioral, eye-gaze and ERP data*. We hypothesized

(a) a faster RT and higher accuracy for incongruent trials in PDF block compared to RDF block due to the dominant operation of proactive mode (which also produce a lower level of conflict cost);

(b) a slower RT and lower accuracy for Dist-Abs trials in PDF block compared to Dist-Abs trials in RDF to indicate the behavioral cost associated with the activation of proactive filtering in PDF block (i.e., larger filtering cost in PDF vs. RDF).

(c) a larger magnitude of N2 for incongruent trials in RDF block compared to PDF (= signaling the detection of competing stimulus and response representation and evidence of reactive attention control).

(d) a larger FSW magnitude for Dist-Abs trials in PDF compared to RDF block (=indicating greater difficulty in response generation in absence of distractors, thus evidence of proactive attention control).

(e) increased overt attentional deployment (dwell time) toward the target AOI and reduced attention deployed toward the distractors AOI in Dist-Abs trials in PDF compared to RDF block.

(2) Aim 2. *To examine whether the introduction of the threat of shock enhances PDF and RDF mechanisms which can be observed through behavioral, eye-gaze and ERP data.* We discussed earlier the enhancing effects of state anxiety on cognitive performance using the translational method of the threat of shock, however, it is not yet clear whether this enhancing effect would generalize to both RDF and PDF modes of cognitive control or it would distinctively enhance one versus another. Previous evidence support this enhancement only in favor of reactive control (perhaps due to an overall arousing state), but it is equally important to examine whether this enhancement would have any benefit for an already-established proactive mode to filter out distractors. Overall, the shock makes the RDF mechanism to resemble that of PDF through increased vigilance and preemptiveness, therefore reducing the differences between the PDF-RDF blocks observed in the safe condition.

Thus, we hypothesized

a) an overall faster RT and higher accuracy for all trials in the shock condition compared to safe across all types of trials.
b) in the shock condition, due to increased vigilance and preemptiveness in RDF block, we expect no difference in RT and accuracy between incongruent trials of PDF and RDF blocks, hence comparable conflict cost is expected in RDF and PDF. Similarly, this increased proactiveness of target processing was hypothesized to result in no statistical differences between filtering cost of RDF and PDF.
c) an increased preemptiveness taking place in RDF under the shock condition due to hypervigilance effect of shock, thus resulting in a relatively smaller N2 magnitude for incongruent trials in RDF with no statistical difference between RDF and PDF is expected. (= overall enhanced conflict resolution).
d) the threat of shock induces effortful, preemptive response generation due to activated proactiveness in both RDF and PDF blocks, thus, with increased FSW amplitude of Dist-Abs trials in RDF, both RDF and PDF blocks should show similar heightened FSW magnitudes with no significant differences being expected.
e) increased dwell time toward the target AOI and reduced dwell time toward the distractors AOI in Dist-Abs trials for both RDF and PDF blocks under the threat of shock, due to shock-induced deficient scanning of visual field and excessive and/or inflexible disengaging from the center target and surrounding distractors.

2. Methods

2.1. Participants and procedure

A hundred one neurologically healthy undergraduate and graduate students (females = 71; Age_{Mean} = 21.8, Age_{SD} = 4.4) recruited from UWM participated in this study. The study protocol was reviewed and approved by the IRB committee at UWM. Participants completed all blocks of safe or shock conditions sequentially in a counterbalanced order (all safe and all shock, or vice versa). This single experimental session lasted about 2 hours and compensation was provided in forms of course extra credit and $10 in exchange. Of total recruited sample, the data of 28 participants (27%) were not included in the final analysis plan due to the following reasons: poor accuracy lower than chance level[1] (n = 9; reflected through lack of attention and effort particularly on incongruent trials), withdrawal (n = 2), completed only either safe or shock (n = 4), noisy EEG data/ no event codes (n = 13); therefore, the final sample included 73 individuals (females = 51; Age_{Mean} = 22, Age_{SD} = 4.9).

2.2. Experimental task design

As described earlier, this experiment took advantage of the novel context manipulation design proposed by Marini et al. (2013, 2016) to explore PDF and RDF using only one task. The study utilized the Erikson arrow Flanker task (see Fig. 1; Eriksen & Eriksen, 1974) with three trial types (congruent [> > > > >], incongruent [> > < > >], & Dist-Abs[>   ]) incorporated into three blocks to create different levels of expectations for conflicting information: Pure block (presenting only the Dist-Abs trials with no flanking distractors), RDF mixed block (RDF; 60% congruent, 20% incongruent, and 20% Dist-Abs trials; created to trigger RDF), and PDF mixed block (PDF; 60% incongruent, 20% congruent, and 20% Dist-Abs;

[1] Participants who showed on average poor accuracy (<=50%) on incongruent trials within RDF and PDF blocks of Shock and The safe conditions were removed from the analysis. This criterion was implemented because incongruent trials played a significant role to address the hypotheses of the study and understanding the difference between PDF and RDF blocks.

created to trigger PDF). The task indexes "conflict-cost" (i.e., incongruent RT – congruent RT) and "filtering-cost" (i.e., Dist-Abs RT in Mixed blocks – Dist-Abs RT in Pure block). The entire tasks consists of 450 trials divided into 9 blocks, with Pure blocks having 45 trials (100% Dist-Abs) and RDF and PDF mixed blocks having 60 trials (the total trial distribution was configured by the congruency proportion outlined above).

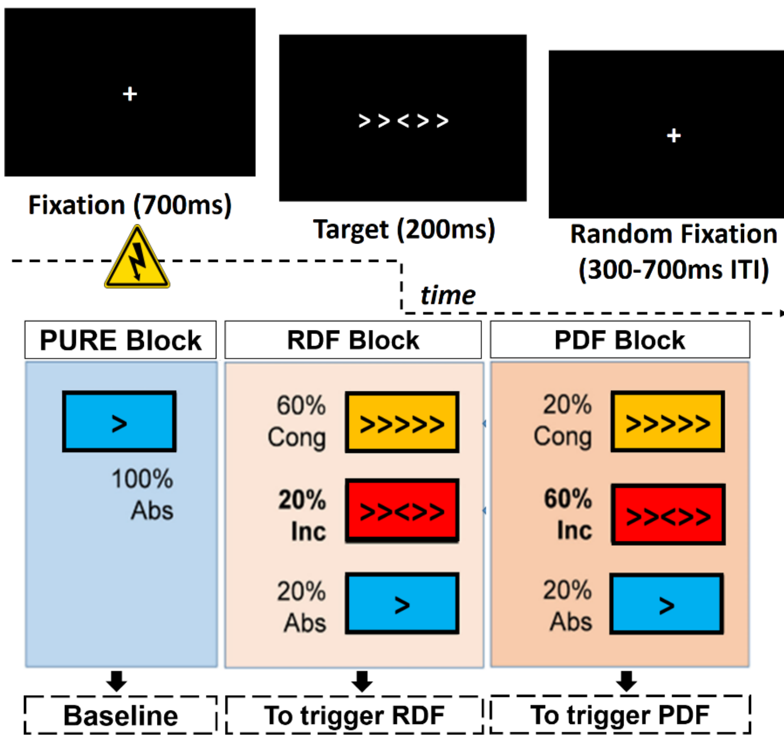

Figure 1. The Flanker task scheme and block design. The upper figure shows the Flanker task scheme where electrical stimulation was delivered randomly during fixation. The lower figure shows the task 3 blocks design with varying proportion combinations. Cong=Congruent; Inc=Incongruent; Abs=Distractor-Absent. RDF & PDF= Reactive & Proactive Distraction Filtering. Portions of this figure are obtained from Marini et al., 2016.

Each block instructed participants which congruency proportion is going to be presented and asked them to respond as quickly and accurately as possible with a right and left mouse click to the target direction. Each trial started with a fixation on the center of screen for 700ms followed by one of the three arrow stimuli (congruent, incongruent, Dist-Abs) presented for 200ms until a response was made. The inter-trial interval was a fixation presentation with a fixed (700ms) and random duration between 300-700ms, adding up a total ITI varying between 1000-1400ms. The stimuli were presented on a black screen with a white fixation cross at the center. The area covering target and flanking arrows on the visual field subtended 3.03° × 10.86° with the target arrow replacing the fixation cross.

2.3. Shock procedure

Shock implementation was carried out using a constant current stimulator device (STEMEPM; BIOPAC systems, Inc., USA, CA). The device was programmed through E-Prime software (Psychology Software Tools, USA, PA) to deliver an electrical stimulation with < 2ms pulse length on participants' right ankle via two electrodes. A shock work-up was implemented prior to the shock condition to gauge the adequate level of individual shock tolerance. Shock intensity for each participant was established based on their rating of 7, where zero was "no painful at all" and 7 was "painful but still tolerable". Up to a total of 16 electrical simulations were programmed to be randomly delivered throughout the shock portion of the Flanker task. The randomization scheme was setup to deliver at least one shock within each block up to maximum 2 in Pure and 3 in each of the Mixed blocks. Participants were also told they could stop participating in the shock condition if the pain was gradually intolerable. They were also encouraged to let the experimenters know if they were habituated to the shock intensity to readjust the threshold (no participant reported habituation). Trials that immediately followed a shock were discarded from all data analyses. After each task block for both safe and shock conditions, participants rated their level of anxiety on a scale of 0-7. The shock electrodes were detached during the safe condition.

2.4. Electrophysiological recording

Electroencephalogram (EEG) was obtained from 32 Ag-AgCl electrode cap (the 10/20 International System of Electrodes) referenced to the left mastoid using a DC amplifier (Advanced Neuro Technologies, B.V. Netherlands). Impedances were maintained below 20K and data were digitized at 500 Hz. Horizontal electrooculogram (EOG) activity was recorded from electrodes placed 1 cm to the left and right of the external canthi and vertical EOG activity was recorded from two electrodes placed above and under the right eye and were all referenced to the left mastoid. Offline data processing was done using EEGLAB (Delorme & Makeig, 2004), and ERPLAB (Lopez-Calderon & Luck, 2014). EEG data was re-referenced to the average of the left and right mastoids and filtered (Butterworth band-pass of 0.1-30Hz; 24db/octave). Data visual inspection and removal of eye-blink were performed following independent component analyses using EEGlab. Data is then epoched for correct trials segmented from -200 to 800ms from the onset of the stimulus with a baseline-correction of 200ms. N2 and the FSW amplitudes are calculated as the post-stimulus mean amplitudes at frontocentral channels (F3, Fz, F4,FC1,FC2) in the 250-400ms and the 650-750ms for N2 and FSW, respectively (Larson et al., 2014; Patel & Azzam, 2005). Trials are automatically rejected (7.8% on average) if vertical EOG exceeded ±80µV and horizontal EOG exceeded ±60µV (Luck, 2014). Participants with trials greater than 20% excessive artifact are removed from data analyses (n=6). For remaining participants, the average numbers of retained trials was 92.2%.

2.5. Eye-gaze data recording

A chin-holder was used to stabilize participants' head movements and fixate the distance between the head and the display screen (22 inch). The eye-tracker device (SMI RED250; SensoMotoric Instruments, Teltow, Germany) was placed immediately below the monitor (a 22-inch Dell monitor which ran at 1680 X 1050 resolution with 60Hz refresh rate) where the task was presented and eye position from the right eye was sampled at 60Hz. Two areas of interest (AOI) were defined: *Target AOI* which surrounded the target stimulus on the center of the screen and *Distractors AOI* which covered the area of the screen where distractor arrows flanked the target arrow (Fig. 2). Given short distance between target and flanking arrows, we used one of the sensitive eye-gaze parameters, namely eye dwell time. Dwell time is defined as the total duration of all gaze fixations and duration of saccades as soon as they enter the AOI within 0 - 700ms post-stimulus interval (i.e., 2 SD above the overall average RT).

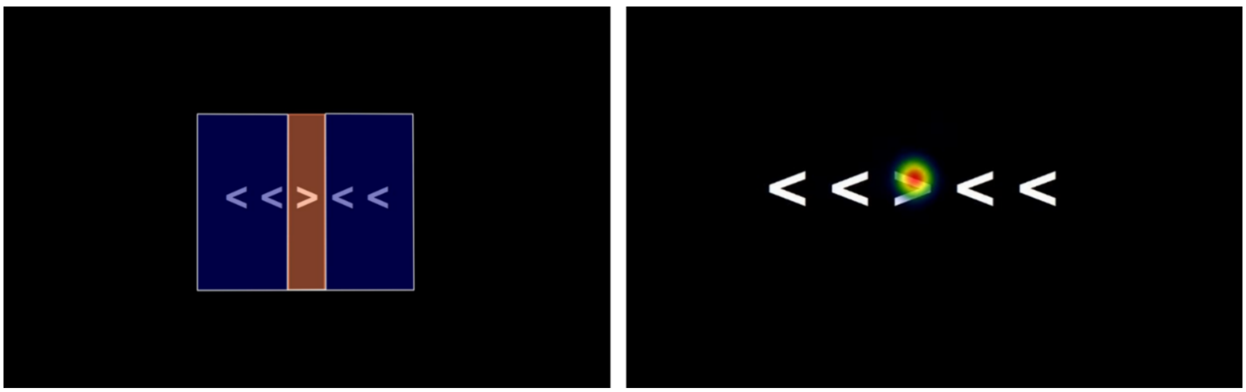

Figure 2. The left figure shows the two AOIs (Target: brown, Distractors: dark blue). **The right figure (enlarged) shows a sample heat map of aggregated dwell time for an incongruent trial.**

3. Analysis plan

We took advantage of multilevel modeling (MLM; aka linear mixed models) for the analyses of behavioral and ERP data which is a robust method ideal for repeated measures designs with strengths to account for random effects (subject level variance), handling of missing observations, and modeling of heteroscedasticity (i.e., non-constant variances of the subject level; Brauer & Curtin, 2018; Judd et al., 2012). Each mixed-effects model used the following formula:

$$y_i = X_i\beta + Z_i b_i + e_i$$

where y_i is a vector values of dependent variable for the participant i^{th}, Xi is a matrix of p independent variables (IV) for the participant i^{th},, β is a vector of p beta weight estimates for every fixed effect IV in X_i, Z_i is a matrix of q random effect IVs, b_i is a vector of q random effect estimates, and e_i is a vector of the model fit residuals. For behavioral data, we removed RTs faster than 200ms and slower than upper 3 standard deviations (i.e., 3% of trials on average per paritipants) for individual participants to be consistent with a recent review paper (Braem et al., 2019). We treated each participant as random effects with trials of RTs and ACCs as dependent variables nested within each participant. For ERP data, each participant and EEG electrode of interest were treated as crossed random effects, thus, dependent variables (N2 or FSW components) are nested within participants and electrodes (Volpert-Esmond et al., 2018; Von Gunten et al., 2018). Fixed effects of Condition (Safe & Shock) X Block (PDF & RDF) X Trial type (e.g., Congruent & Incongruent) were used as predictors in both RT and ERP models. For RT models, we allowed the intercept and the slope of Condition to randomly vary by participant and, for ERP data, we allowed the intercept and the slope of Condition to vary by electrode nested within participant. Restricted maximum likelihood estimation was used with an unstructured covariance matrix to test the significant effects and Satterthwaite's method for approximation of denominator of degrees of freedom. The R lme4 and lmerTest packages was implemented for the analyses (Bates et al., 2015; Kuznetsova et al., 2017). If any of the model resulted in the degrees of freedom larger than 1000, we used *z* statistics (Volpert-Esmond et al., 2018). In order to control for potential inflation of type I error, we applied the Bonferroni-Holm method (1979) as one of the most stringent multiple comparison correction methods to test simple effects of trial types or blocks. As recommended by Brauer & Curtin (2018), we report *F* values with Satterthwaite's method (i.e., one of the most conservative methods) for approximation of denominator of degrees of freedom.

3.1. Power analysis

To produce an adequate power (0.8) for repeated measures ANOVAs implemented for eye-tracking data, the G*Power analysis software (Mayr et al., 2007) estimated that we needed 68 participants for a small effect size of 0.21, an alpha level of 0.05, and an inter-measure correlation coefficient of 0.5. However, considering that usable EEG data depends on several factors to be minimal to obtain reliable data (e.g. lower body movements, lower eye-blink; Larson et al., 2014) and our own experience in the first study with the Flanker task, we recruited 101 participants to overcome any possible EEG data limitation and be consistent with previous studies. The final sample size also fulfilled the requirement of sufficient power (0.8) for MLM. With an estimated power of 0.8, an estimated intra-class correlation (ICC) of 0.3, a type I error of 0.05, a small effect size of 0.1, a level-2 cluster size of 70 (=number of participants), the model required at least 480 trials per participant. This number was lower than the total trials per participant in this study (=900; Lüdecke, 2020).

3.2. Manipulation check and data inspection

Following a recent report of possible interference of carry-over effects of previously induced shock on safe blocks (Jeong & Cho, 2020; Pedersen & Larson, 2016), we examined the two-way interaction of Condition (Shock or Safe) by Counterbalanced order (i.e., whether the experiment was started with Safe or Shock blocks) on anxiety ratings during each block completion. We observed that the shock condition overall resulted in significantly larger anxiety ratings ($F(1, 853) = 488.5$, $p < 0.10^{-9}$) compared to the safe condition. We also found a significant interaction between Condition and Order ($F(1, 853) = 57.6$, $p < 0.10^{-4}$).

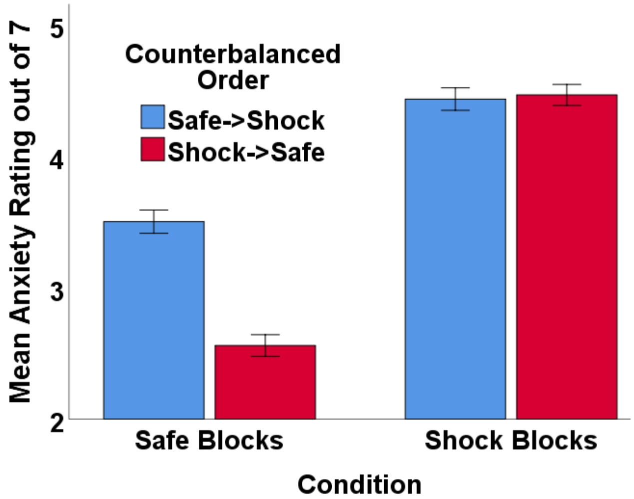

Figure 3. **Anxiety rating as a function of condition and counterbalanced order.** *This shows an overall significant higher anxiety rating for shock condition regardless of counterbalanced order. Anxiety rating was significantly lower for those who completed the safe condition after a shock condition compared to those who did safe before shock. Error bars shows standard errors.*

While anxiety rating was not significantly different between the shock blocks, participants who started the safe condition after the shock condition reported significantly lower anxiety relative to those who did the safe condition before the shock condition. ($t(1, 853) = 7.81$, $p < 0.10^{-13}$). We also did find a significant interaction effect of Condition by Order on overall RT ($F(1, 72) = 8.53$, $p < 0.004$), and accuracy ($F(1, 72) = 10.23$, $p < 0.002$). However, the follow-up simple effect analysis on RT with the Bonferroni-Holm correction method (1979) revealed there was no significant difference between the order of safe blocks ($z = 1.59$, $p = 0.53$) as well as shock blocks ($z = 0.26$, $p = 0.99$), indicating that RT in the safe condition was not significantly influenced by preceding shock blocks. (Fig. 4). A similar simple effect analysis on accuracy showed a significantly higher accuracy for shock blocks that followed safe blocks relative to those first-run shock blocks ($z = 2.62$, $p < 0.03$), however no significant differences was observed in terms of safe blocks and their corresponding order ($z = 0.43$, $p = 0.7$; Fig. 4).

Therefore, the carry-over effect of shock did not seem to significantly influence the safe blocks in terms of RT and ACC, however, in order to investigate the first hypothesis, we ran the first analysis separately on those safe blocks which were administrated before the shock blocks and those safe blocks which were done after the shock block to isolate any potential effect of shock threat (i.e., carry-over effect).

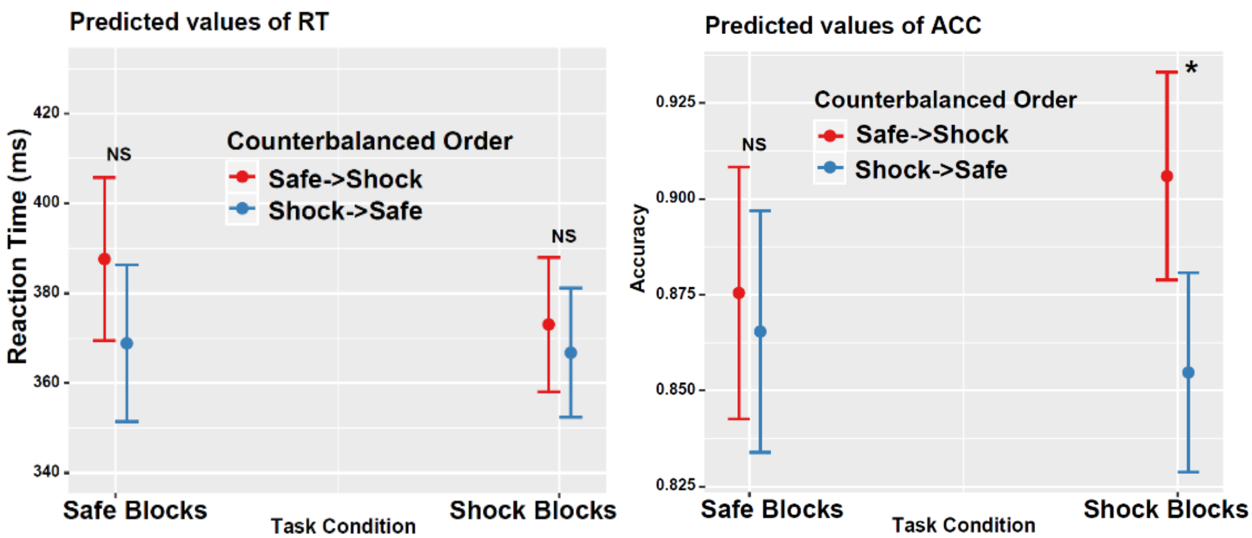

Figure 4. Predicted (estimated marginal means) values of RT and Accuracy as functions of blocks and counterbalanced order. *The left figure shows a non-significant faster RT for safe blocks completed after shock blocks compared to safe blocks preceded shock blocks and the right figure shows larger accuracy for shock blocks implemented after safe blocks relative to first-goer shock blocks. ACC = accuracy; NS = Not Significant. * =* p *< 0.001.*

With N = 35, we were able to replicate the behavioral results of the pilot study for RT and accuracy such that we indeed observed a significantly larger RT ($t(34)= 2.08$, $p <0.04$) and lower accuracy ($t(34)= 2.04$, $p <0.04$) for incongruent trials in RDF block relative to incongruent trials in PDF, indicating that proactive cognitive control resulted in faster incongruent RT and higher accuracy. However, this result did not hold for those safe blocks which followed shock blocks (N = 38). A similar analysis on Dist-Abs trials did partially replicate the first study after exclusively looking at first-goer safe blocks. Both Dist-Abs_{RDF} ($t(34)= 5.15$, $p <10^{-5}$) and Dist-Abs_{PDF} ($t(34)= 3.05$, $p <0.001$) showed significant larger RT compared to Dist- Abs_{Pure} block, and similar result was observed for those safe blocks that followed the shock condition (Dist-Abs_{RDF}: $t(37)= 3.12$, $p <0.003$); Dist-Abs_{PDF}: $t(37)= 4.16$, $p <0.001$). Considering accuracy, only

Dist-Abs_{RDF} showed significantly better accuracy relative to Dist- Abs_{Pure} for the isolated first-run safe blocks ($t(34)= 2.79$, $p <0.008$).

This accuracy result is reversed for those isolated safe blocks which followed the shock blocks, with only Dist-Abs_{PDF} showing better accuracy relative to Dist-Abs_{Pure} ($t(37)= 3.23$, $p <0.003$). Our analysis on the isolated safe blocks mostly replicated the founding of the first experiment by showing that PDF mechanism produced faster RT and higher accuracy for incongruent trials, indicating a lower level of conflict cost. We also observed that both PDF and RDF mechanisms produced filtering cost which was only seen for PDF in the first study. Overall, although the threat carry-over effect was not significantly observed across anxiety rating, RT and ACC, we decided to add the counterbalanced order factor to all of our analyses as a covariate in the models to account for any potential order effect. This procedure will ensure that we can control for the influence of the order of blocks while testing the main hypotheses of the study to investigate whether the threat of shock has enhancing effect on PDF and RDF mechanisms.

3.3. Behavioral

3.3.1. Incongruent and congruent trials

In order to investigate behavioral aspects of hypotheses 1a&b and 2a pertaining whether the threat of shock has enhancing effects on PDF and RDF relative to the safe condition, we conducted separate 2 X 2 X 2 Condition (Safe & Shock) by Block Type (RDF & PDF) by Trial Type (Congruent & Incongruent) mixed models for RT and accuracy of congruent and incongruent trials in different blocks and threat condition. We observed an overall faster RT for the shock condition relative to safe ($F(1, 75) = 6.66$, $p < 0.01$; Table 1; Appendix 1a&b), however, there was no overall significant difference between shock and the safe conditions in accuracy ($F(1, 80) = 2.06$, $p = 0.15$; Fig. 5; Table 2).

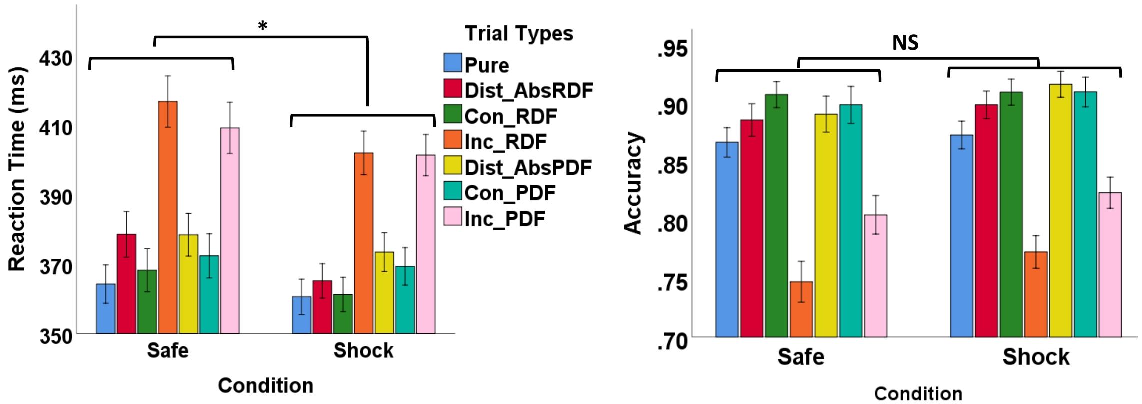

Figure 5. **Mean of RT and Accuracy across trials and task condition.** *The left figure shows RT and the right figure shows accuracy across the conditions. Shock produced overall significantly faster RT relative to the safe condition, but no significant difference between safe and shock was observed in accuracy. Error bars represent standard error of the mean. * =* p *< 0.01; NS = Not significant.*

This result highlighted that, regardless of the counterbalance order, while presence of shock gave rise to overall faster responses of incongruent and congruent trials relative to safe, it did not affect overall accuracy in a statistically significant way. We did not find a significant three-way interaction among Condition, Block, & Trial Type for either RT or accuracy. However, we observed two-way interaction in RT between Condition and Trial Type (Congruent & Incongruent; $F(1, 34980) = 11.28$, $p < 10^{-3}$) and between Condition (Safe & Shock) and Block (RDF & PDF; $F(1, 34975) = 6.32$, $p < 0.02$). No such two-way interactions were found for accuracy. Simple effect analyses demonstrated that the overall RT difference between incongruent and congruent trials (i.e., collapsed across RDF and PDF) is significantly smaller in the shock condition versus the safe condition ($z = 2.58$, $p < 0.009$). This finding suggested that after controlling for order effect, not only the threat of shock produced faster responses, but also did it result in an overall smaller difference between incongruent and congruent trials when compared to the difference between incongruent and congruent in the safe condition.

3.3.2. Conflict cost

Moreover, the significant interaction between Condition and Block allowed us to look into the differences between RDF and PDF in terms of conflict cost. As described earlier, conflict cost were calculated based on following forms:

$$\text{Conflict Cost}_{\text{RDF}} = \text{Incongruent}_{\text{RDF}} - \text{Congruent}_{\text{RDF}}$$

$$\text{Conflict Cost}_{\text{PDF}} = \text{Incongruent}_{\text{PDF}} - \text{Congruent}_{\text{PDF}}$$

We first observed that RDF conflict cost produced significantly lower cost relative to PDF in both safe ($z = 3.94$, $p < 0.10^{-4}$; Table 3) and the shock conditions ($z = 2.93$, $p < 0.01$; see Fig. 6), indicating that PDF mechanism is associated with smaller conflict cost compared to RDF regardless of the threat of shock.

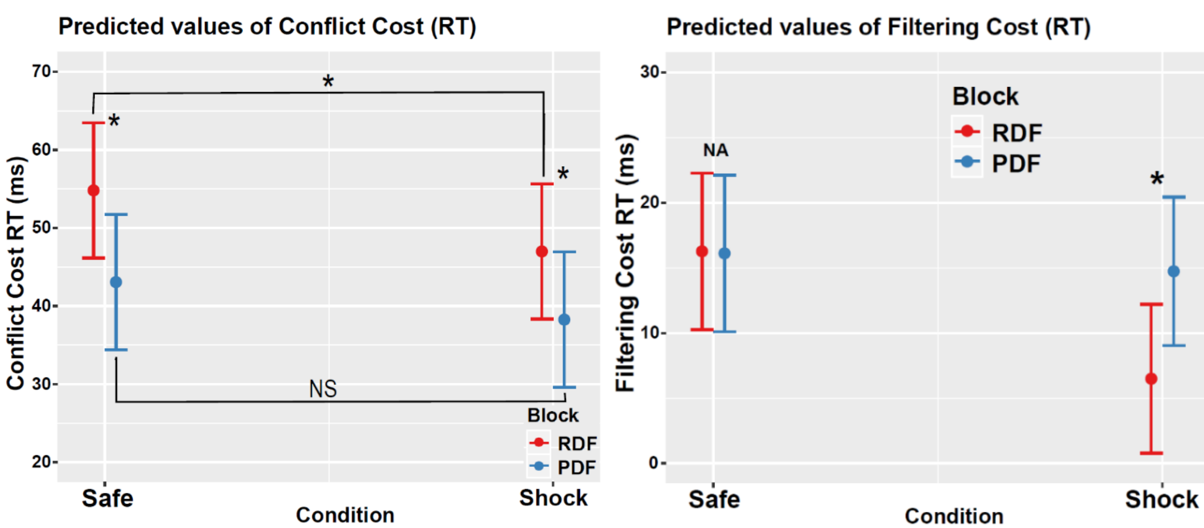

Figure 6. Predicted values (estimated marginal mean scores) of RT Conflict and Filtering costs across blocks and task condition. *The left figure shows conflict cost and the right figure shows filtering cost. Conflict cost PDF was significantly smaller than RDF in both safe and shock conditions. Shock conflict cost RDF was significantly smaller than safe conflict cost RDF, but no difference between shock & safe in conflict cost PDF. Only shock showed significantly larger filtering cost PDF relative to RDF. Error bars represent confidence intervals. NS = Not Significant.* * = p *< 0.01.*

We further observed that RT conflict cost_{RDF} in the shock condition is smaller than RT conflict cost_{RDF} in the safe condition ($z = 2.62$, $p < 0.02$), however, there was no such statistical difference between RT conflict $cost_{PDF}$ of the shock and safe conditions. This finding suggested that while the presence of the threat of shock did produce an overall lower conflict cost, its effect was more pronounced on conflict $cost_{RDF}$ compared to conflict $cost_{PDF}$ (Fig. 6).

3.3.3. Distractors-Abs trials and filtering cost

We also ran separate 2 X 3 Condition (Safe & Shock) by Block Type (Pure, RDF & PDF) mixed models for RT and accuracy to compare Dist-Abs trials as functions of condition and blocks. We observed an overall faster responses under the shock condition relative to safe ($F(1, 74.4) = 5.05$, $p < 0.02$; Appendix 2a&b) as well as a significant interaction between Condition and Block for RT ($F(1, 20381) = 7.69$, $p < 10^{-3}$; Fig. 5; Table 1 & 2). We did not find any significant main effect of Condition nor we observed a significant interaction effect of Condition by Block for accuracy. Our simple effect analyses on RT revealed a larger RT for Dist-Abs_{PDF} relative to Dist-Abs_{RDF} in the shock condition ($z = 3.81$, $p < 0.001$), however, there was no difference between Dist-Abs_{PDF} and Dist-Abs_{RDF} for the safe condition ($z = 0.11$, $p = 1$). We did similar analyses on filtering cost based on the following calculation:

$$\text{Filtering Cost}_{\text{RDF}} = \text{Dist\_Abs}_{\text{RDF}} - \text{Pure}$$
$$\text{Filtering Cost}_{\text{PDF}} = \text{Dist\_Abs}_{\text{PDF}} - \text{Pure}$$

These analyses on filtering cost demonstrated that the shock condition generated significantly larger filtering cost in PDF block than in RDF block ($z = 3.12$, $p < 0.01$) while no statistical difference was observed between filtering cost of PDF and RDF under the safe condition ($z = 0.05$, $p = 0.1$; Fig. 6; Table 4). These results provided evidence that the threat of shock distinctively caused slower responses to trials in which expected distractors were absent, however, it did not influence accuracy in a statistically significant way. We also ran a correlation analysis between conflict and filtering costs in PDF mode to see if we can replicate the observed negative correlation in the pilot study. We did not find a correlation between these two costs in PDF block neither in the safe condition ($r(71) = .18$, $p = 0.1$) nor in the shock ($r(71) = .14$, $p = 0.2$).

3.4. Eye-gaze

3.4.1. Incongruent and congruent trials

As explained in the method section, two AOIs were defined (*Target AOI* surrounds the target stimulus on the center of the screen and *Distractors AOI* covers the area of the screen where distractor arrows flanked the target arrow). We ran 2 X 2 X 2 Condition (Safe & Shock) by Block Type (RDF & PDF) by Trial Type (Congruent & Incongruent) repeated measures ANOVAs on each AOI separately to examine the effect of shock on dwell time given different trial types. We only found an overall larger dwell time for the safe condition relative to shock in the Target AOI, indicating that on average the target stimulus captured longer eye-gaze under the safe condition compared to shock ($F(1, 70) = 7.02$, $p < 0.01$, $\eta_p^2 = 0.09$; Table 5 & 6; Fig. 7).

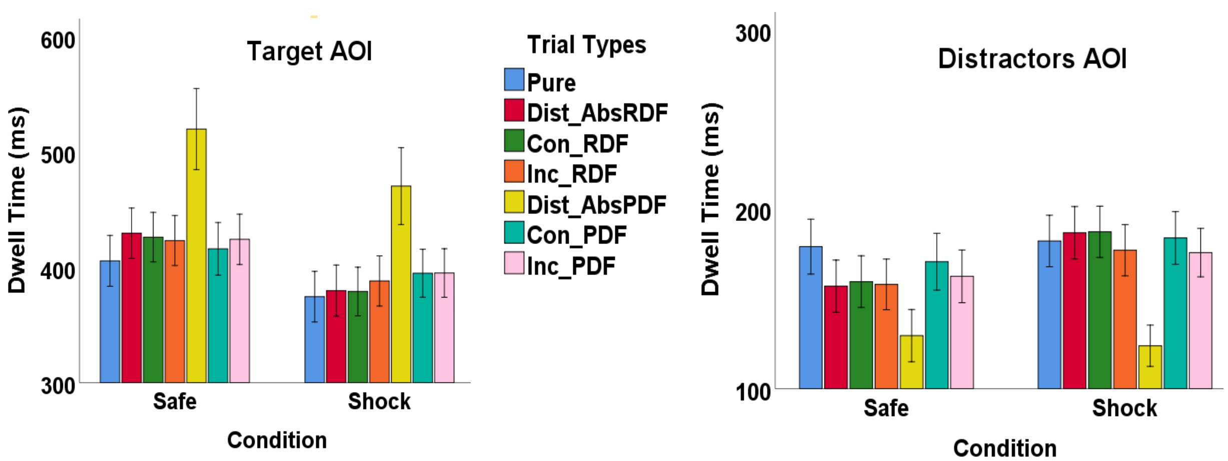

Figure 7. Mean of dwell time across trials and task condition. *The dwell time averages are presented on the left figure for Target AOI and on the right figure for Distractors AOI. Error bars represent standard error of the mean.*

A similar analysis on the Distractors AOI did not produce significant main effect results as well as significant two-way or three-way interactions. Thus, it indicated that there was no difference on amount of time spent on the flanking distractors of incongruent and congruent trials under the safe and shock conditions.

3.4.2. Distractors-Abs trials

To test the same hypothesis for dwell time of Dist-Abs trials, we ran 2 X 3 Condition (Safe & Shock) by Block Type (Pure, RDF & PDF) repeated measures ANOVAs on each AOI separately. Considering Target AOI, we found generally a lower dwell time (collapsed across blocks) under the shock condition relative to safe ($F(1, 70) = 7.79$, $p < 0.007$, $\eta_p^2 = 0.1$; Fig. 7). We also found a significant main effect of Block ($F(1, 99.97) = 37.67$, $p < 10^{-5}$, $\eta_p^2 = 0.35$): dwell time averaged across shock and safe revealed that Dist-Abs_{PDF} captured significantly longer eye-gaze on the target stimulus compared to Dist-Abs_{RDF} ($t(70)= 6.64$, $p < 10^{-4}$ and Dist-Abs_{Pure} ($t(70)= 5.13$, $p < 10^{-4;}$ Table 5 & 6), while there no significant difference between Dist-Abs_{RDF} and Dist-Abs_{Rure}.

We conducted a similar analysis on Distractors AOI of Dist-Abs trials. We did not find a significant main effect of Condition, but we observed a significant main effect of Block ($F(1, 139.74) = 36.23$, $p < 10^{-5}$, $\eta_p^2 = 0.34$) as well a significant interaction effect of Condition by Block ($F(1, 131.4) = 4.91$, $p < 0.01$, $\eta_p^2 = 0.06$). Follow-up analyses showed that only significant comparisons that survived the correction were those with smaller dwell time for Dist-Abs_{PDF} relative to Dist-Abs_{RDF} (Safe: $t(70)= 3.95$, $p < 10^{-5}$; Shock: $t(70)=7.74$, $p < 10^{-4}$) and Dist-Abs_{Pure} (Safe: $t(70)= 4.89$, $p < 10^{-4}$; Shock: $t(70)= 6.39$, $p < 10^{-4}$). These results overall provided evidence that all trials under the shock condition were associated with shorter eye-gaze on the target stimulus relative to safe. Also, the shock condition did not affect the flanking distractors in incongruent and congruent trials. The overall pattern of eye-gaze results suggested both safe and shock conditions replicated the finding observed in the pilot study. Therefore, unlike our expectation that the threat of shock would generate significantly longer dwell time on the target stimulus in both PDF and RDF blocks due to an increased vigilant state, we observed that only PDF showed long eye-gaze on the target stimulus which might potentially point out to the behavioral cost associated with the absence of expected distractors (i.e., filtering cost).

3.5. Event-related potentials

As explained in the analysis plan, each participant and EEG electrode of interest are treated as crossed random effects, and dependent variables (N2 or FSW components) are nested within participants and electrodes to take full-advantage of single-trial-level structure of the data. (See Fig. 8 for data representation).

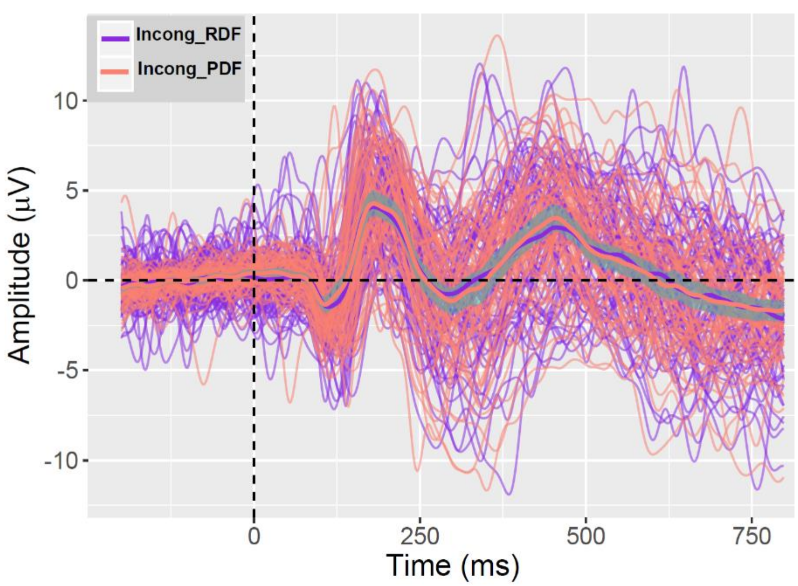

Figure 8. Representation of individual ERP waveforms and corresponding mean ERPs. *The waveforms depict a collective pattern of ERPs from 200ms before the stimulus onset (time = 0) to 800ms post-stimulus presentation. MLM allowed us to take into account randomness of individual ERPs (e.g., there is more variability for RDF as shown in the plot). Aggregated ERPs and bootstrapped confidence intervals are superimposed by thicker wave and shaded area, respectively.*

The mean of N2 and FSW were submitted to a mixed random slope model with fixed effect of Condition (Safe & Shock) X Block (RDF & PDF) X Trial type (Incongruent & Congruent) and a random slope effect of Condition.

3.5.1. N2 ERP analysis

In regards to N2, after controlling for counterbalanced order, we did not find a significant three-way interaction of Condition, Block and Trial type ($F(1, 144055) = 0.025$, $p = 0.87$; Table 7). The lack of significant three-way interaction was also seen in the behavioral data. However, we observed an overall significant larger N2 for shock relative to the safe condition ($F(1, 434) = 6.21$, $p < 0.01$). We also observed a significant two-way interaction of Condition by Block ($F(1, 144256) = 10.37$, $p < 0.001$) and of Condition by Trial type ($F(1, 144161) = 13.464$, $p < 10^{-3}$). Simple effect analyses on N2 collapsed across trials (incongruent & congruent) revealed that there was larger N2 RDF relative to PDF in the safe condition which was not significant after the correction ($z = 1.21$, $p = 0.2$; Fig. 9, 10 & 11). However, this trend was similar with the behavioral data where we observed larger conflict cost associated with RDF under the safe condition, indicating some associations between larger conflict cost RDF and larger N2 RDF in the safe condition. Under the threat of shock, we observed an opposite pattern of results than the safe condition, such that PDF block generated larger magnitude of N2 relative to RDF ($z = 3.31$, $p < 0.002$; Fig. 9, 10 & 11). Our behavioral data showed larger conflict cost for RDF in shock, thus we expected to see a larger N2 magnitude for RDF under shock, however, the observed N2 amplitudes under shock was not consistent with our expectation. Further simple effect comparisons on N2 averaged across blocks (RDF & PDF) demonstrated a larger magnitude of N2 for incongruent versus congruent in the safe condition ($z = 8.83$, $p < 10^{-8}$) and no difference between them in the shock condition. This suggested that the effect of shock potentiated N2 amplitude of congruent trials to be comparable to that of incongruent trials.

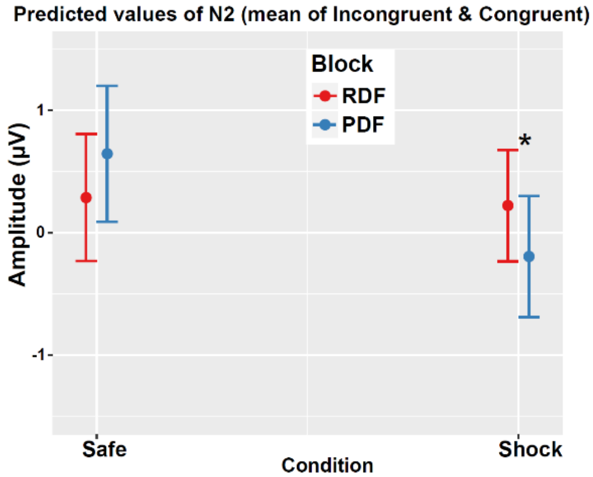

Figure 9. Estimated marginal means of N2 averaged for incongruent and congruent trials across block and condition. Lower values (more negative values) indicate a greater magnitude of N2. *Error bars represent confidence intervals. * = p < 0.01*

3.5.2. FSW ERP analysis

We focused our analysis of FWS on Dist-Abs trials to obtain neural evidence of increased filtering effort under these trials. We found a significant interaction effect of Condition (Safe & Shock) by Block (Pure, RDF, PDF) for Dist-Abs trials ($F(1, 83906) = 3.17$, $p < 0.04$; Fig 10; Table 8).

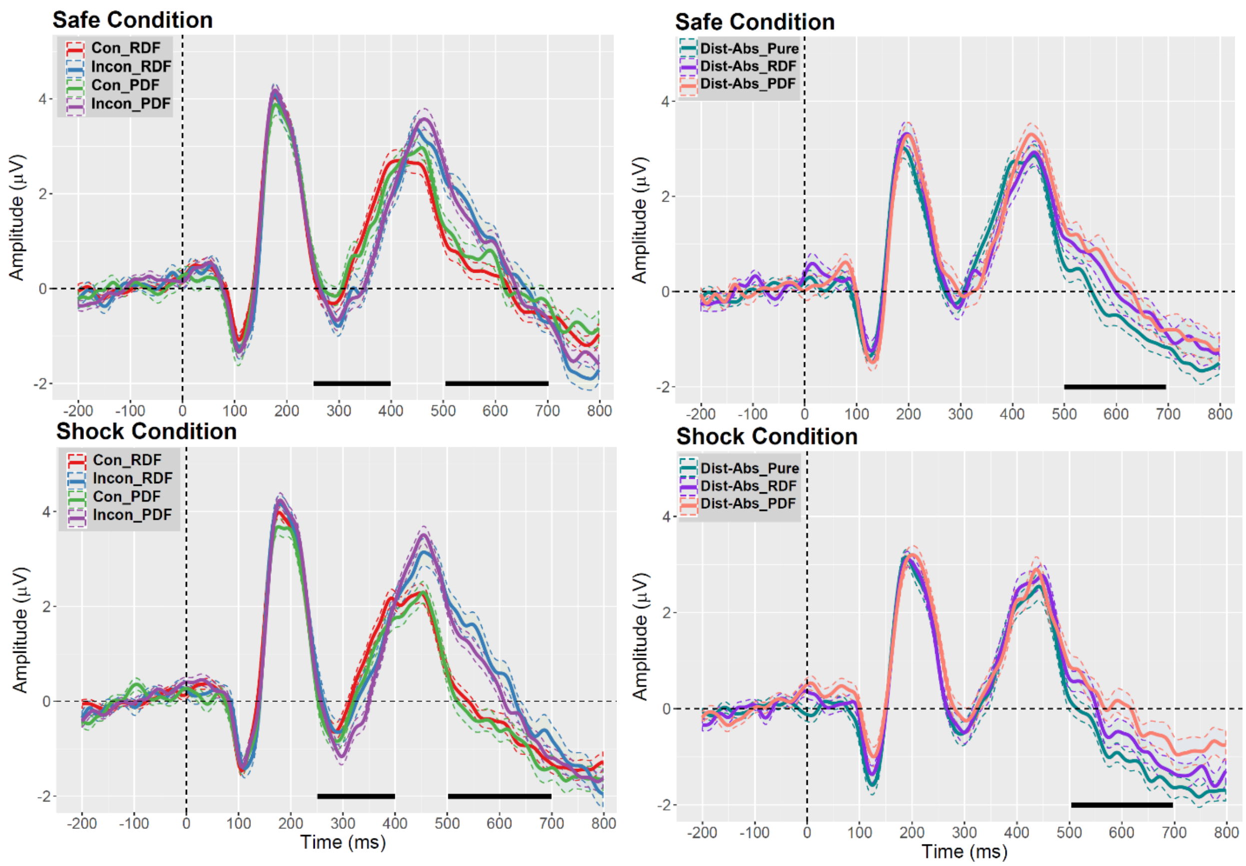

Figure 10. Grand average waveforms from correct trials of Flanker task. *Upper (safe) & lower (shock) figures show average waveforms across a group of frontocentral electrodes (F3,F4,Fz,FC1,FC2) for different trial types across time. Horizontal black bars indicate significant areas (*p *< 0.05). Dashed, shaded areas are representing standard error. Con = Congruent; Incon = Incongruent. Dist-Abs = Distractor-Absent.*

Follow-up comparison results showed that while Dist-Abs$_{PDF}$ produced significantly larger FSW relative to Dist-Abs$_{RDF}$ in the presence of the threat of shock ($z = 3.94$, $p < 10^{-4}$), there was no significant difference between these two trials under the safe condition (Fig. 12). This finding was consistent with the behavioral data where we observed larger filtering cost for PDF relative to RDF under shock and no difference between them in the safe condition. Similarly, the shock FSW result replicated that of the pilot study, and indicates that larger amplitude of the FSW is associated with magnitude of cognitive effort to generate a response when there was a mismatch in the anticipated stimuli set (i.e., the absence of anticipated distractors).

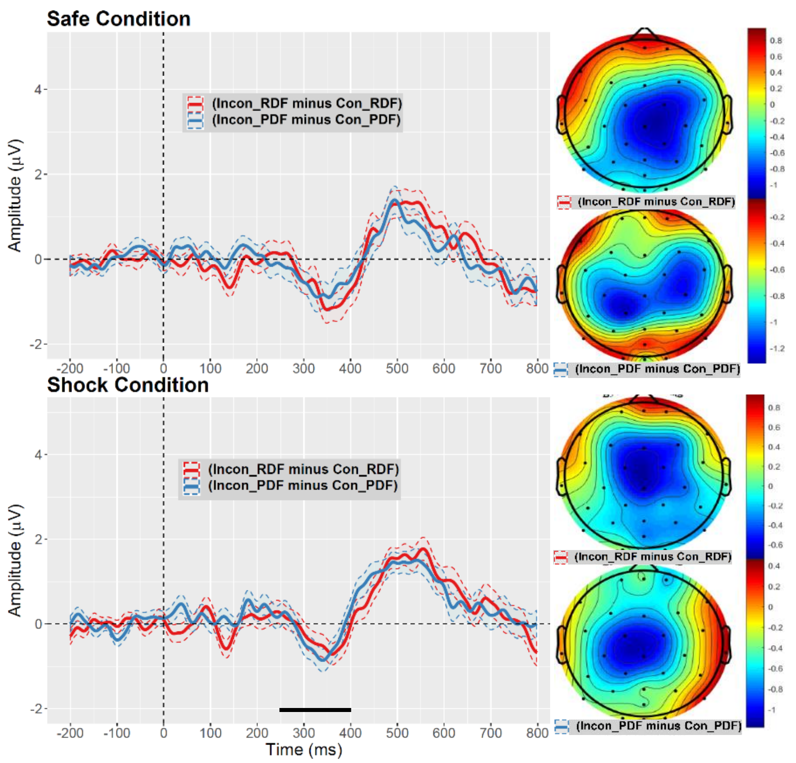

Figure 11. Difference waveforms and topographic maps from correct trials of Flanker task. *Upper (safe) and lower (shock) figures show the average difference waveforms between incongruent and congruent trials given their corresponding blocks (RDF or PDF). No statistical difference of N2 was observed between Safe RDF vs. PDF, however, Shock resulted in significantly larger N2 in PDF vs. RDF. Right plots show topographic distribution of incongruent minus congruent ERP differences at 300ms (N2). Darker blue shows larger magnitude of incongruent at frontal sites. Dashed, shaded areas are representing standard error. Con = Congruent; Incon = Incongruent. Horizontal black bar is significant areas (*p < 0.05*).*

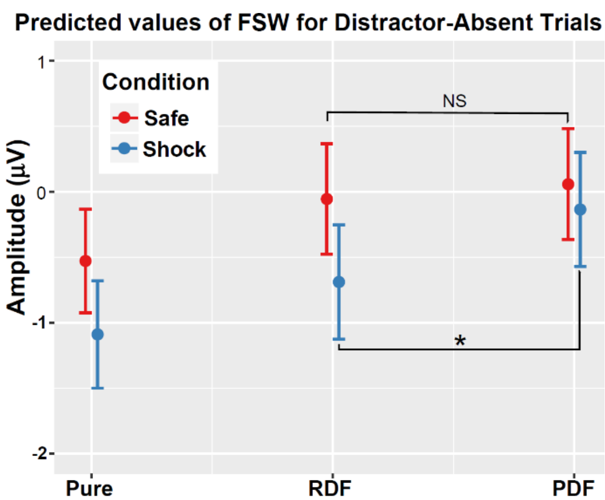

Figure 12. Difference average waveforms and topographic maps from correct trials of Flanker task. *Upper (safe) and lower (shock) figures show the average difference waveforms between incongruent and congruent trials given their corresponding blocks (RDF or PDF).*

4. Discussion

This study examined how the threat of shock would affect RDF and PDF modes of cognitive control. We used a Flanker task with varying proportion congruency (Gratton et al., 1992) under the safe condition and under the threat of unpredictable shock, and provided behavioral, ERP and eye-gaze evidence on how state anxiety would influence these two mechanisms. Previous evidence (Jeong & Cho, 2020; Yang et al., 2018) supports the shock-induced enhancement only in the reactive control condition (perhaps due to an overall arousing state), but it is equally important to examine whether the threat of shock would have any benefit for the proactive mode that might be already established to filter out distractors. In the following sections, we address the findings of this study based on the proposed hypotheses.

4.1. What are RDF and PDF and their corresponding behavioral, ERP, & eye-gaze characteristics

The recent developments in the theories of cognitive control suggest that RDF relies on adjustments of attentional control in response to distractors or conflict and is assumed to be the “default mode” of cognitive control due to its resource efficient mechanism (Braver, 2012; Chiew & Braver, 2017; Marini et al., 2013). On the other hand, PDF is an effortful, sustained attentional deployment that preemptively enhances selective target processing prior to distracting inputs (Appelbaum et al., 2012; Bugg & Crump, 2012; Mäki-Marttunen et al., 2019). These studies suggested that although PDF mechanism pre-emptively reduces the taxing effect of goal-irrelevant distractors (conflict cost), the PDF activation might actually render behavioral cost (filtering cost) when expected distractors are absent (Marini et al., 2013, 2016). Through two experiments (our pilot study and the no-shock block of the current study), we replicated the behavioral results of previous studies using a variant of a Flanker task utilizing the distraction context manipulation paradigm (Marini et al., 2013, 2016). We showed that PDF significantly lowered the conflict-cost while increasing the filtering-cost, indicating that although PDF is beneficial when distraction presents, its recruitment is not without costs when expected distraction is absent. The overall accuracy of PDF was also significantly larger than RDF, which shows that proactive control enhances accuracy of distraction suppression. Eye-tracking data revealed that compared to RDF, PDF is characterized by prolonged fixations on the central target with reduced attention deployed toward the peripheral area, suggesting that the heightened filtering-cost in PDF may be associated with more narrow, demanding, and effortful attentional focus on the target with inflexible or reduced attentional deployment toward the peripheral areas.

The ERP result of the pilot study and this study (the safe portion) demonstrated that N2 amplitude was greater (= a more negative potential) in RDF compared with PDF, showing that PDF operates pre-emptively in anticipation of forthcoming distractors resulting in an overall lower level of conflict. The pilot study showed that FSW was more positive for Dist-Abs trials in PDF compared to RDF blocks (i.e., a neural evidence of larger response generation effort associated with PDF). However, in this study we observed that both Dist-Abs PDF and RDF showed more positive FSW relative to Dist-Abs Pure, but they were not statistically different from each other which was consistent with the corresponding behavioral data. Taken together, these results suggest that N2, in response to incongruency, may trigger a greater cognitive monitoring signal driven from ACC (Botvinick et al., 2001) to up-regulate attentional focus in an ongoing task, while FSW was reflective of the magnitude of effortful cognitive control implemented to generate a response when there was a mismatch in the anticipated stimuli set (i.e., the absence of anticipated distractors; Clayson & Larson, 2011; Larson & Clayson, 2014).

The increased RT filtering cost in PDF block and its associated larger FSW are in line with previous reports (Czigler et al., 2006; Escera & Corral, 2007; Pazo-Alvarez et al., 2003) indicating that preemptive, effortful characteristics of PDF creates expectations of distracting stimuli (e.g., adopting a strategic distraction suppressison mechanism at lower level visual cortex to preventively suppress distractors (Marini et al., 2013, 2016)). When the anticipated distracter is absent, it may render the generation of proper response more laborious due to the violation/mismatch in expectancy. Thus, the operation of PDF appears to be beneficial in reducing the level of conflict stemming from incongruent trials, which is well aligned with the expectancy. However, the preemptive attentional regulation by PDF may actually turn out to be counterproductive when the expectancy is violated by the absence of distracters. In contrast, RDF does not induce such preemptive regulatory processes, and would be more efficient in processing the distraction-free trials by relying on the default, reactive, and more stimulus-driven process. Overall, we showed that PDF is an effortful, sustained attentional deployment that preemptively enhances selective target processing prior to distracting inputs, thus resulting in lower RT conflict cost and lower magnitude of N2 for distracting trials, but higher RT filtering cost and larger FSW amplitude for trials without distractors. On the other hand, RDF involves the late adjustment of attentional control in response to infrequent distractors or conflict, thus resulting in higher RT conflict cost and larger magnitude of negative-going N2 for distracting trials, but no elevation in the behavioral filtering cost or FSW amplitude.

4.2. The role of threat in proactive and reactive distraction filtering

One of the key aims of this study was to understand the effect of the threat of shock on PDF and RDF modes of cognitive control. This study provided evidence in support of many previous studies showing that increased state anxiety through the threat of shock brings about overall faster RT when compared against non-shock, safe situations (Hu et al., 2012; Robinson, Vytal, et al., 2013). Particularly, we found that heightened vigilance and preemptiveness incurred via presence of shock reduced longer response delays between infrequent presentations of incongruent trials versus frequent presentations, although it did not influence accuracy. However, we still observed significantly larger conflict cost (i.e., the difference between incongruent and congruent trials) for RDF block relative to PDF. Interestingly, though, we found that the threat of shock had some unique effects on RDF block, such that there was a significantly lower conflict cost of RDF shock condition versus safe but there was no such difference between PDF conflict cost of shock condition versus safe. This outcome provided evidence that although the threat of shock had an overall enhancing effect on RT across all trials, this effect was more pronounced on RDF trials compared to PDF. This enhancing effect of shock closely replicated other studies in which the threat of shock resulted in reduced stimulus-response conflict (Hu et al., 2012; Robinson, Vytal, et al., 2013). More importantly, it fits nicely with the growing evidence that the threat of shock uniquely boosts performance on high-interference trials (i.e., incongruent) and reduces stimulus-response conflict effects (Hu et al., 2012; Robinson, Vytal, et al., 2013; Yang, Miskovich, Larson 2018).

Consistent with our behavioral result, we found no evidence suggesting significant differences between incongruent PDF and RDF in the shock condition in terms of N2 amplitudes. However, our N2 result demonstrated that the shock condition overall generated more negative N2 amplitude (larger magnitude) compared to safe. This result was in line with the wealth of studies showing that anxiety is associated with larger magnitudes of frontal-midline ERP components (i.e., N2, FRN, ERN) shown to be reflective of cognitive control processes during emotionally-neutral cognitive tasks (e.g., a Flanker task; Cavanagh & Shackman, 2015). Additionally, we found that the threat of shock on average created larger magnitudes of N2 during PDF block relative to RDF. And when we examined the overall difference between incongruent and congruent trials (averaged across both RDF and PDF), we did not find any significant results, indicating that, unlike the safe condition, the overall larger magnitude of incongruent N2 versus congruent N2 disappeared under the threat of shock. This result for the shock condition did not follow its corresponding behavioral conflict cost, unlike the almostcoherent results of N2 and RT conflict cost for the safe condition. We interpret this inconsistency to suggest that the idea of conflict cost and its associated neural correspondence (putatively N2) is plausible when there is a marked difference between highly conflicting trials (i.e., incongruent) in RDF relative to PDF. This is important because incongruent trials are the main factor in the calculation of conflict cost (incongruent – congruent) and their larger RT fluctuation can directly influence conflict cost (Krug & Carter, 2012). Relatedly, we did not see a difference between incongruent trials of RDF and PDF in the presence of shock and the observed lower RT conflict cost for PDF in the absence of related neural signature (N2) might simply reflect a smaller dissimilarity between incongruent and congruent trials in PDF, relative to RDF. In the same vein, it is also possible that under the threat of shock the facilitatory effect of PDF on congruent trials might have been reduced, which contributed to reducing the difference between incongruent and congruent trials in PDF. However, in regards to the safe condition, RT of incongruent trials in RDF indeed were significantly larger than in PDF, which suggests the presence of a larger conflict cost in the RDF relative to PDF condition. This is also consistent with the greater N2 amplitude observed for incongruent trials in the RDF condition.

In line with the pilot study, we found that the threat of shock produced a larger filtering cost for PDF versus RDF, while accuracy was left intact. This showed a more laborious response to the absence of distractors in PDF under shock. With shock enhancing both RDF and PDF, we interpreted this result to provide evidence that even in the face of overall induced preemptiveness, it appears that characteristics of PDF more strongly increased expectations of stimulus attributes for distracting stimuli than those of RDF (e.g., adopting a strategic distraction suppression mechanism at lower level visual cortex to preventively suppress distractors (Marini et al., 2013, 2016). This increased tendency brought about larger filtering cost due to the violation/mismatch in expectancy which was further supported by neural evidence of FSW. Accordingly, we found that the magnitude of FSW in the shock condition closely resembled the corresponding behavioral results, such that Dist-Abs PDF generated a significantly larger magnitude compared to RDF. As mentioned earlier, FSW results for the safe condition were also consistent with the observed behavioral indices. Thus, it seems FSW is more reflective of shock and safe behavioral results relative to N2. Therefore, it is convincing to believe that although the overall pattern of data reveals shock-induced hypervigilance across the board, prepotent expectations of distractors still produced strategic cost to reorient attention toward the target stimulus and offset the violation of mismatch in expectancy (Marini et al., 2016).

The eye-gaze result of the shock data supported the observed faster RT of the behavioral data by showing that overt attentional deployment in the form of dwell time was significantly lower on the target stimulus in the shock, relative the safe condition. Similar to the safe condition, there were no substantial differences between eye-gaze processing of incongruent and congruent trials in PDF versus RDF blocks. However, just like the safe condition, Dist-Abs PDF under shock caused a significantly larger dwell-time on the target stimuli (i.e., Target AOI) in comparison to Dist-Abs RDF and Pure. This result was consistent with the shock RT and FSW results for Dist-Abs PDF in this study as well as our hypothesis based on the pilot study, and provided complementary evidence that the shock PDF mode of cognitive control increased overt attentional deployment toward the target AOI and reduced attention deployment toward the distractors AOI in trials with a mismatch in the anticipated stimuli set (lack of distractors). With little data regarding how attention engages in and disengages from target stimuli under shock, some studies have argued that PDF may prioritize target features and/or actively suppress the anticipated distractor (Geng, 2014), while others believe that active suppression of distraction as in the case of PDF always follows the initial attention to distraction and may not be preemptively suppressed (Moher & Egeth, 2012). In a meta-analysis review, Lisk et al. (2020) reported youths with anxiety had significantly lower overall dwell time on threat versus neutral stimuli compared to control groups. Inconsistently, another meta-analysis review concluded that anxious adults relative to non-anxious spent greater free viewing time and initial vigilance for threat stimuli (Armstrong & Olatunji, 2012). Most of these studies, however, did not directly measure eye-gaze characteristics of attentional control under an imminent threating condition and used tasks with emotionally salient stimuli (e.g., emotional Stroop task; Armstrong & Olatunji, 2012; Cisler & Koster, 2010; Lisk et al., 2020). Nevertheless, in this study, although we did not find any correlation between RT of Dist-abs PDF and dwell-time of Dist-abs PDF under shock, it is possible that the longer attentional focus on the target stimulus might be due to an overcompensation arising from readjustment of attentional spotlight from vigilantly scanning peripheral to reorient towards the center target stimulus. In turn, this disengagement and reorientation might have contributed to the behavioral cost observed with PDF.

4.3. Explanation of relevant theories for the observed effect of threat on distraction filtering

This unique improvement of RT of incongruent RDF is in line with converging evidence of an enhancing effect of shock on physiological arousal and performance enhancement particularly on tasks relying on stimulus-driven attention processing such as Flanker (Baas, Milstein, Donlevy, & Grillon, 2006; Cornwell et al., 2007; Robinson et al., 2013). This suggests that uncertainty about receiving shock enhances general perceptual processing by lowering the threshold of detecting extrinsically and intrinsically salient stimuli (Robinson et al., 2011). Using a Stroop task, Yang et al. (2018) reported a better performance in the shock, relative to the safe condition in response to infrequent (30%) incongruent trials, suggesting an enhancing effect of shock on reactive cognitive control (Yang et al., 2018). However, they did report a non-significant RT difference for shock versus safe in rare incongruent trials although shock generated faster RT. They also tested the effect of shock on proactive mode through the AX-CPT task and reported that the threat of shock resulted in more false alarm, thus disturbing proactive control. Overall, Yang et al. (2018) concluded that the threat of shock "facilitates reactive control" through enhanced activity of the ACC-driven conflict monitoring system and impairs proactive control through reduced processing efficiency on tasks requiring inhibitory abilities which is subserved by dlPFC (Yang et al., 2018). Our behavioral data is consistent with their interpretation. However, our results suggest that this enhancement of reactive control is simply due to increased, sustained preemptiveness in the presence of threat rather than simply operating in a phasic, reactive manner. This interpretation could be true because in non-shock RDF, the "default mode" of control is reactive in response to infrequently occurring distracting stimuli to efficiently use attentional resources; consequently the proactiveness is dampened. By the introduction of physiological arousal through shock, the phasic reactive mode of RDF shifts toward being tonically proactive across multiple trials which brings about faster RT in incongruent trials (Braver et al., 2008). If the reactive control was more engaged, we would have expected to see a more sluggish response to incongruent trials in RDF as well as a more negative amplitude of N2 to up-regulate attentional focus in response to insufficient goal-directed attention (Botvinick et al., 2001; Braver, 2012). However, we observed that N2 RDF was not larger than N2 PDF in the shock condition and, in fact, the opposite was observed.

This result is inconsistent with some of previous studies showing that high-trait anxious individuals showed larger behavioral and electrophysiological indices (i.e., N450 as a family of ACC driven amplitudes) of conflict adjustment (larger reactiveness) compared to low-trait anxious individuals (Osinsky et al., 2010, 2012). These researcher (Osinsky et al., 2010, 2012) argued that while high-trait anxious individuals heavily rely on reactive cognitive control to compensate for reduced cognitive control, low-trait anxious individuals generally recruit sustained mode of proactive cognitive control. In a fMIR study, False et al. (2008) also demonstrated that low-anxious individuals showed transient, as opposed to sustained, activation of WM related brain regions after being exposed to an anxiety-related video, similar to the brain activation of high-anxious individuals in response to a neutral-content video (False et al., 2008). This discrepancy between our result and previous results could simply be explained by the magnitude of threat context where a painful, physical shock produced larger physiological arousal to incur sustained cognitive control relative to fearful stimuli or high-trait anxiety. In fact, one study provided evidence that participants showed larger startle responses and reported more averseness with a neutral stimuli associated with a shock relative to fearful faces (Glenn et al., 2012). Therefore, our result suggested that physiological arousal incurred through the threat of shock could possibly shift reactive mode of cognitive control to that of proactive.

Our results pertaining to proactive mode are consistent with the wealth of studies showing impairment or dampening of proactive cognitive control under threatening condition (Robinson, Vytal, et al., 2013; Vytal et al., 2016; Ward et al., 2020; Yang et al., 2018). While we observed the threat of shock improved behavioral RDF relative to safe RDF, this threatening condition did not improve PDF of shock versus safe. The neurocognitive and eye-gaze indices of PDF (i.e., larger FSW and larger dwell-time on target stimulus) showed that proactive mode was indeed in place under the threat of shock and this laborious, effortful mechanism was associated with behavioral cost (larger filtering cost). The Flanker task utilized in this experiment required stimulus-driven sustained attentional processing and did not require active maintenance of memorandum in the PDF block. Thus it appeared that the adverse effect of shock only dampened the proactive effectiveness, instead of completely removing the effect of PDF relative to RDF (Yang et al., 2018). This is particularly evident as there was no difference between behavioral PDF in shock and safe, however, shock PDF versus shock RDF still produced lower conflict related cost.

ACT account can provide insight about the obtained result (Eysenck et al., 2007). While ACT predicts that processing efficiency of attention control is disrupted via anxiety through impaired attentional inhibition, updating, or shifting, it also predicts that these adverse effects of anxiety might be reduced when compensatory mechanisms are engaged. Therefore, when enhanced efforts are involved, anxiety may not disturb one's cognitive performance on a task (Derakshan & Eysenck, 2009). Similarly, we observed that participants' "processing efficiency" (RT) was improved under threat of unpredictable shock relative to safe while they maintained the same quality of performance (accuracy). Hence, in PDF, it is possible that induced arousal state via threatening condition might have encouraged participants to engage in more laborious, compensatory mechanisms to sustain similar levels of accuracy while more efficiently processing stimuli versus safe (Eysenck et al., 2007). Relatedly, participants in this experiment could still maintain proactiveness under threat, though with a lesser extent. Overall our findings are consistent with the ACT (Eysenck et al., 2007) which posits that anxiety impairs efficient functioning of the goal directed attentional system and enhances processing by the stimulus-driven attentional system. Our data suggest that this recruited compensatory mechanism was particularly in place during threat, as this Flanker task was not very difficult relative to other known cognitive tasks (e.g., WM tasks or AX-CPT; Vytal et al., 2016). Thus, per ACT account, the adverse effect of threat might reduce available resources for compensation only when task difficulty depletes resources for compensation (Derakshan & Eysenck, 2009; Eysenck et al., 2007). In line with this idea, one study (Balderston et al., 2017) recently reported that intraparietal sulcus (the main player of attention orienting) has a key role in pathological anxiety and its hyperactivation under the threat of shock could explain "the paradoxical facilitation of performance on tasks that require an external focus of attention [i.e., tasks requiring sustained attention such as Flanker or Stroop] and impairment of performance on tasks that require an internal focus of attention [e.g., WM tasks or AX-CPT]."

We believe the shock-induced larger N2 under PDF can further support this idea. This finding partially challenges some of the recent reports (Shackman et al., 2011, 2016) suggesting that anxiety and generally negative affects (such as fear) are an integrated part of cognitive control processes which are controlled under a domain-general functionality of the midcingulate cortex (i.e., one of the main generators of N2-like components). If larger N2 magnitude was entirely signaling the detection of competing stimulus and response representation in the absence of a prepared response to up-regulate attentional focus, we should have instead observed a lower N2 for the shock condition. Therefore, it is likely that N2 reflected different characteristics of cognitive processing under the threat of unpredictable shock and was not simply "cranking up" attentional processing in response to insufficient/habitual responses to direct goal-driven behaviors. Additionally, it is also possible that frequent exposure to high-distracting stimuli under the threat of shock might actually potentiate the N2 component to be sensitive to a higher degree of stimulus-response discrepancies (Pedersen & Larson, 2016; Shackman et al., 2011). In line with this, studies have shown that high conflicting trials may indeed trigger the activation of ACC as an aversive signal associated with negative affect (Botvinick, 2007; Fritz & Dreisbach, 2013). Thus, under threatening condition, ACC might show a heightened sensitization to conflict trials. The sensory gating hypothesis might also provide some justification of this potentiation, and it asserts that some filtering mechanisms at sensory level enable elaborative processing of certain stimuli (Grillon & Davis, 2007). Startle response potentiation is one of well-known physiological responses which provided evidence of sensory gating (Grillon et al., 1991). In a similar vein, two studies have shown that healthy individuals, as opposed to anxious patients, showed increased sensory gating (startle-physiological potentiation) under a threatening state (Cornwell et al., 2007; Grillon & Davis, 2007). Together, these findings suggested that while the shock condition resulted in generally lower behavioral conflict indices relative to safe, it showed larger conflict-related neural activity (N2) when compared against the safe condition. Additionally, it is likely that N2 under the threat of shock could be potentiated to high-conflicting stimuli when there is a higher likelihood of them.

4.4. Some methodological considerations

In light of some recent reports highlighting a carryover effect of threat (Jeong & Cho, 2020; Pedersen & Larson, 2016), we investigated whether the safe condition was truly safe and "shock/threat-free" by examining the interaction between counterbalanced order and condition (safe and shock) on anxiety rating, RT and accuracy to shed light on any potential carry-over effect of shock to the safe condition (Jeong & Cho, 2020; Pedersen & Larson, 2016). We observed larger anxiety ratings for the shock condition overall compared to safe, indicating that participants indeed experienced heightened levels of state anxiety during the shock condition, regardless of the counterbalanced order. We also found that participants who started the safe condition after the shock condition reported significantly lower anxiety relative to those who did the safe condition before the shock condition. This result highlighted that at least perceptually participants did not experience heightened state of anxiety after completing a shock condition, and indeed they reported the opposite effect. Similarly, we did not find any substantial evidence of this shock carry-over effect to the safe condition on RT and accuracy. However, we did see larger accuracy for the shock condition completed after the safe compared to those shock condition that started the experiment (i.e., completed before the safe). Although this result was not directly related to the shock carry-over effect to the safe blocks (due to the absence of any accuracy difference in the order of safe condition), it pointed to some degree of practice effect in accuracy involving the shock condition. Interestingly, this result occurred while no RT differences were observed for the order of the shock condition, therefore, it could not be simply attributed to a speed-accuracy trade-off (Jeong & Cho, 2020). Additionally, while the shock-induced higher cognitive performance due to a physiologically-aroused state is well-documented in the literature (Balderston et al., 2017; Pedersen & Larson, 2016; Robinson et al., 2011; Robinson, Vytal, et al., 2013), this finding suggested that facilitated cognitive performance via the threat of shock maybe even more pronounced when there is a practice effect involved (Torrisi et al., 2016). Nevertheless, the analysis of a subset of participants who started the safe condition before shock (n=35) showed faster RT and larger accuracy for incongruent trials of PDF blocks relative to RDF. This result pointed to the same observation obtained in the pilot study, indicating a better performance in response to incongruent trials under proactive mode of cognitive control (Marini et al., 2013, 2016). Consistent with the first study, the analysis of conflict cost also supported this result by showing that PDF block produced significantly smaller RT cost compared to RDF in the safe condition, signifying that PDF may sustained attentional deployment that pre-emptively enhances selective target processing prior to distracting inputs, thus resulting in lower RT conflict cost (Appelbaum et al., 2012; Bugg & Crump, 2012; Marini et al., 2013, 2016; Mäki-Marttunen et al., 2019). Thus, this new approach helped us to isolate any potential shock carryover effect by replicating the prior reports.

To our knowledge, the multimodal methodology used in this experiment is first in the literature to combine behavioral, EEG, and eye-tracking information to shed light on the interaction of different modes of cognitive control and anxiety via the translational method of electric shock. The growing literature of relationship between anxiety and cognitive performance can significantly benefit from this approach, in that each methodology may serve as a cross-validation of the findings of other methodologies and move researchers closer in their investigation of the causality in this relationship, instead of association findings. Particularly, this multimodal approach enabled us to examine dynamics of interaction of PDF and RDF with high state anxiety while utilizing high temporal-resolution EEG methodology along with eye-tracking recording.

The Combination of a multimodal approach with multilevel modeling of trial-level behavioral and ERP data improved the robustness of the findings of this study. While the traditional methodology (e.g., repeated measure ANOVA) assumes that averaged data across trials is constant for a given participant, multilevel modeling would not require such an assumption and is capable of accounting for random variances among individuals in task's trials and blocks, therefore, significantly increasing the power to capture lager effect sizes (Judd et al., 2012; Lotfi et al., 2020). This is particularly important in the context of EEG as previous studies (Volpert-Esmond et al., 2018; Von Gunten et al., 2018) showed large randomness associated with the nature of ERP data (a larger fluctuation of ERP signals across individuals). In this study we implemented a random slope mixed model to account for individual differences in the effect of induced-state anxiety (as a random slope effect) on behavioral and ERP dependent variables.

Prior studies reported that individual differences play a key role in terms of the processing of aversive signals in the context of cognitive performance and anxiety controlled by ACC (Dreisbach & Fischer, 2015). Given the strong effect of the threat of shock on physiological arousal and cognitive performance, accounting for these intra- and inter-individual differences is critical for this type of studies.

Another great advantage of MLM is its ability to robustly handle unbalanced data with missing observations. The threat of physical electric shock generates external sources of noise, and consequently, many effected behavioral and ERP trials should be removed so as not to bias the data. Or there might be some extremely slow or fast trials that should be eliminated because they would heavily skew the results. Therefore, MLM comes out a strong contender in this situation to handle unbalanced data, as opposed to group-averaging approaches (e.g., ANOVA) which might render undesirable effect (Judd et al., 2012). Togerther, we would suggest that future studies implement a multimodal methodoloy approach along with multilevel mixed modeling to reduce various sources of bias with data and inrease robusness in capturing potentially meaningful effects.

5. Limitations and future suggestions

This study should be regarded in the context of some potential limitations. The effects of lower level feature integration and response contingencies or repetition priming on the conflict adaptation have been well-reported in earlier studies (Braem et al., 2019; Jacoby et al., 2003; Schmidt et al., 2007). One of the strengths of this Flanker task compared to previously used versions was the addition of the two stimuli (Dist-Abs right and left) to the original version of the task (i.e., incongruent right, incongruent left, congruent right, congruent left) which could reduce stimulus-stimulus or response-response contingencies. We further removed any consecutive trial types to test the effect of repetition priming on the observed slowing RT. The behavioral result was still replicated. Thus, the faster RT to frequent incongruent trials could not be simply attributed to repetition priming or response contingencies. Considering the result from another point of view, one might argue that the observed behavioral cost in the safe condition simply reflected a speed-accuracy trade off due to the automatic engagement of a more cautionary attentional strategy resulting in slowing down. Our analysis of accuracy rejected this idea because if there was a tradeoff between RT and accuracy, there should have been a larger accuracy for the infrequent appearance of distracting stimuli, however, the accuracy was not different between RDF and PDF in the safe condition. We also do not believe that the larger RT slowing of Dist-Abs_PDF in the shock condition was simply a consequence of rare probability of this trial type, specifically, because the proportion of Dist-Abs trials in both blocks (RDF & PDF) was the same (= 20%). The results of this study rise questions and suggestions that should be addressed in future studies. We would suggest that future study, after counter-balancing the order of condition within participants, conduct the safe and shock conditions on separate days to further reduce the possibility of a carryover effect of the shock condition to safe. We also suggest that the effect of the threat of shock on reactive and proactive modes of cognitive control be examined using other well-known tasks of proportion congruency effect (e.g., Stroop or Simon tasks) to further understand this effect on congruency adaptation. As explained in the introduction, these translational experiments with healthy individuals may provide evidence in regards to the relationship of cognitive performance and anxiety. Therefore, we suggest, using our multimodal approach, that future studies try to replicate our results with a population of clinically diagnosed anxious individuals to further disentangle the differences observed in cognitive control between induced state anxiety and trait-anxiety.

6. Conclusion

Through two experiments, we created reactive and proactive control processes in a laboratory setting and replicated the behavioral results of previous studies of RDF and PDF, and further enriched the literature by adding evidence of neurocognitive and eye-gaze indices corresponding to these modes of cognitive control using a highly stringent, multimodal methodology. In the second experiment, we went one step further and examined this methodology under the threat of unpredictable shock and successfully demonstrated that induced-state anxiety, versus safe, has an overall enhancing effect on RT but no effect on accuracy, regardless of mode of cognitive control. However, shock had a unique enhancing effects on reactive control by shifting its mode of operation from "reactiveness" toward "preemptiveness" while having a dampening effect on the proactive mode through using attentional resources and leaving limited capacity for proactivness in the face of highly frequent distractors. The finding of N2 potentiation and longer eye-gaze fixations further supported the idea that PDF mode might have been associated with some compensatory activity under the threat of shock which still resulted in a better overall performance compared to RDF, however, this compensation could not outperform PDF mode under the safe condition. Overall the multimodal approach adopted in this experiment provide ample evidence in support of previous experiments and suggest a replication of this finding with a population of individuals with trait-anxiety to further disentangle the differences observed in cognitive control between induced state anxiety and trait anxiety.

7. Tables

Table 1. Descriptive Statistics of RT.

Condition	Block	Trial	emmean	SE	df	asymp.LCL	asymp.UCL
	PURE	Dist-Abs	363.30	6.21	Inf	348.47	378.14
		Dist-Abs	378.29	6.33	Inf	363.18	393.40
	RDF	Congruent	367.64	6.20	Inf	352.85	382.44
Safe		Incongruent	417.76	6.37	Inf	402.55	432.97
		Dist-Abs	378.17	6.33	Inf	363.06	393.27
	PDF	Congruent	372.27	6.33	Inf	357.16	387.37
		Incongruent	410.76	6.21	Inf	395.94	425.58
	PURE	Dist-Abs	360.01	5.16	Inf	347.69	372.33
		Dist-Abs	364.87	5.29	Inf	352.23	377.51
	RDF	Congruent	360.82	5.14	Inf	348.55	373.10
Shock		Incongruent	403.28	5.34	Inf	390.54	416.02
		Dist-Abs	373.23	5.29	Inf	360.60	385.86
	PDF	Congruent	368.98	5.29	Inf	356.35	381.62
		Incongruent	402.30	5.15	Inf	390.01	414.60

Note. emmean = Estimated Marginal Means; SE = standard error of mean; Inf = infinity; asymp.L/UCL = asymptotic lower/upper confidence level. The emmean is a robust and more accurate representation of the mean of dependent variable after adjusting for covariates in the model. Asymptotic confidence intervals are common reports for MLM due to sufficiently large sample size which approaches infinity for degrees of freedom.

Table 2. Descriptive Statistics of Accuracy.

Condition	Block	Trial	emmean	SE	df	asymp.LCL	asymp.UCL
Safe	PURE	Dist-Abs	0.88	0.01	Inf	0.85	0.91
	RDF	Dist-Abs	0.90	0.01	Inf	0.87	0.93
		Congruent	0.92	0.01	Inf	0.89	0.95
		Incongruent	0.76	0.01	Inf	0.73	0.79
	PDF	Dist-Abs	0.90	0.01	Inf	0.87	0.93
		Congruent	0.91	0.01	Inf	0.88	0.94
		Incongruent	0.82	0.01	Inf	0.79	0.85
Shock	PURE	Dist-Abs	0.88	0.01	Inf	0.86	0.91
	RDF	Dist-Abs	0.91	0.01	Inf	0.88	0.93
		Congruent	0.92	0.01	Inf	0.90	0.95
		Incongruent	0.78	0.01	Inf	0.75	0.81
	PDF	Dist-Abs	0.92	0.01	Inf	0.90	0.95
		Congruent	0.92	0.01	Inf	0.89	0.95
		Incongruent	0.83	0.01	Inf	0.81	0.86

Note. emmean = Estimated Marginal Means; SE = standard error of mean; Inf = infinity; asymp.L/UCL = asymptotic lower/upper confidence level. The emmean is a robust and more accurate representation of the mean of dependent variable after adjusting for covariates in the model. Asymptotic confidence intervals are common reports for MLM due to sufficiently large sample size which approaches infinity for degrees of freedom.

Table 3. Descriptive Statistics of Conflict Cost.

Condition	Block	emmean	SE	df	lower.CL	upper.CL
Safe	RDF	48.78	3.38	104.54	41.11	56.46
	PDF	37.04	3.38	104.54	29.36	44.72
Shock	RDF	40.96	3.28	107.06	33.51	48.42
	PDF	32.24	3.28	107.06	24.78	39.69

Note. emmean = Estimated Marginal Means; SE = standard error of mean; CL = confidence level. The emmean is a robust and more accurate representation of the mean of dependent variable after adjusting for covariates in the model.

Table 4. Descriptive Statistics of Filtering Cost.

Condition	Block	emmean	SE	df	lower.CL	upper.CL
Safe	RDF	14.45	2.58	123.20	8.62	20.28
	PDF	14.29	2.58	123.20	8.46	20.12
Shock	RDF	4.67	2.39	134.42	-0.73	10.07
	PDF	12.92	2.39	134.42	7.51	18.32

Note. emmean = Estimated Marginal Means; SE = standard error of mean; CL = confidence level. The emmean is a robust and more accurate representation of the mean of dependent variable after adjusting for covariates in the model.

Table 5. Descriptive Statistics of Dwell Time for the Target AOI.

Condition	Block	Trial	Mean	SD	n
Safe	PURE	Dist-Abs	405.65	186.37	71
	RDF	Dist-Abs	429.67	183.60	71
		Congruent	426.19	180.92	71
		Incongruent	423.27	182.33	71
	PDF	Dist-Abs	519.95	296.43	71
		Congruent	416.07	192.09	71
		Incongruent	424.30	183.95	71
Shock	PURE	Dist-Abs	374.58	185.04	71
	RDF	Dist-Abs	379.84	187.21	71
		Congruent	379.04	178.20	71
		Incongruent	388.20	183.28	71
	PDF	Dist-Abs	470.51	280.83	71
		Congruent	394.95	175.29	71
		Incongruent	395.13	177.50	71

Table 6. Descriptive Statistics of Dwell Time for the Distractor AOI.

Condition	**Block**	**Trial**	**Mean**	**SD**	**n**
Safe	PURE	Dist-Abs	179.14	128.77	71
	RDF	Dist-Abs	157.13	122.56	71
		Congruent	159.63	121.12	71
		Incongruent	158.07	118.87	71
	PDF	Dist-Abs	129.55	122.80	71
		Congruent	170.74	133.07	71
		Incongruent	162.60	123.74	71
Shock	PURE	Dist-Abs	182.29	120.96	71
	RDF	Dist-Abs	186.87	123.02	71
		Congruent	187.41	120.38	71
		Incongruent	177.16	120.52	71
	PDF	Dist-Abs	123.91	96.94	71
		Congruent	183.98	123.48	71
		Incongruent	175.81	113.80	71

Table 7. Descriptive Statistics of N2 ERP component.

Condition	**Block**	**Trial**	**emmean**	**SE**	**df**	**asymp.LCL**	**asymp.UCL**
	PURE	Dist-Abs	0.18	0.18	Inf	-0.25	0.61
		Dist-Abs	-0.09	0.19	Inf	-0.55	0.36
	RDF	Congruent	0.24	0.18	Inf	-0.19	0.67
Safe		Incongruent	-0.35	0.20	Inf	-0.82	0.11
		Dist-Abs	0.07	0.19	Inf	-0.39	0.53
	PDF	Congruent	0.36	0.19	Inf	-0.10	0.82
		Incongruent	-0.31	0.18	Inf	-0.74	0.12
	PURE	Dist-Abs	-0.11	0.16	Inf	-0.49	0.27
		Dist-Abs	-0.21	0.17	Inf	-0.62	0.20
	RDF	Congruent	0.03	0.16	Inf	-0.34	0.40
Shock		Incongruent	-0.18	0.17	Inf	-0.60	0.23
		Dist-Abs	0.03	0.17	Inf	-0.38	0.44
	PDF	Congruent	-0.19	0.17	Inf	-0.59	0.22
		Incongruent	-0.47	0.16	Inf	-0.84	-0.09

Note. emmean = Estimated Marginal Means; SE = standard error of mean; Inf = infinity; asymp.L/UCL = asymptotic lower/upper confidence level. The emmean is a robust and more accurate representation of the mean of dependent variable after adjusting for covariates in the model. Asymptotic confidence intervals are common reports for MLM due to sufficiently large sample size which approaches infinity for degrees of freedom.

Table 8. Descriptive Statistics of FSW ERP component.

Condition	Block	Trial	emmean	SE	df	asymp.LCL	asymp.UCL
Safe	PURE	Dist-Abs	-0.47	0.14	Inf	-0.81	-0.13
	RDF	Dist-Abs	-0.02	0.16	Inf	-0.41	0.36
		Congruent	0.09	0.14	Inf	-0.24	0.42
		Incongruent	0.60	0.17	Inf	0.20	1.00
	PDF	Dist-Abs	0.22	0.16	Inf	-0.17	0.60
		Congruent	0.43	0.16	Inf	0.05	0.82
		Incongruent	0.69	0.14	Inf	0.35	1.03
Shock	PURE	Dist-Abs	-0.99	0.15	Inf	-1.35	-0.63
	RDF	Dist-Abs	-0.57	0.17	Inf	-0.97	-0.17
		Congruent	-0.52	0.15	Inf	-0.87	-0.17
		Incongruent	0.52	0.17	Inf	0.10	0.93
	PDF	Dist-Abs	0.01	0.17	Inf	-0.39	0.41
		Congruent	-0.59	0.17	Inf	-0.99	-0.19
		Incongruent	0.16	0.15	Inf	-0.19	0.51

Note. emmean = Estimated Marginal Means; SE = standard error of mean; Inf = infinity; asymp.L/UCL = asymptotic lower/upper confidence level. The emmean is a robust and more accurate representation of the mean of dependent variable after adjusting for covariates in the model. Asymptotic confidence intervals are common reports for MLM due to sufficiently large sample size which approaches infinity for degrees of freedom.

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9. Appendices

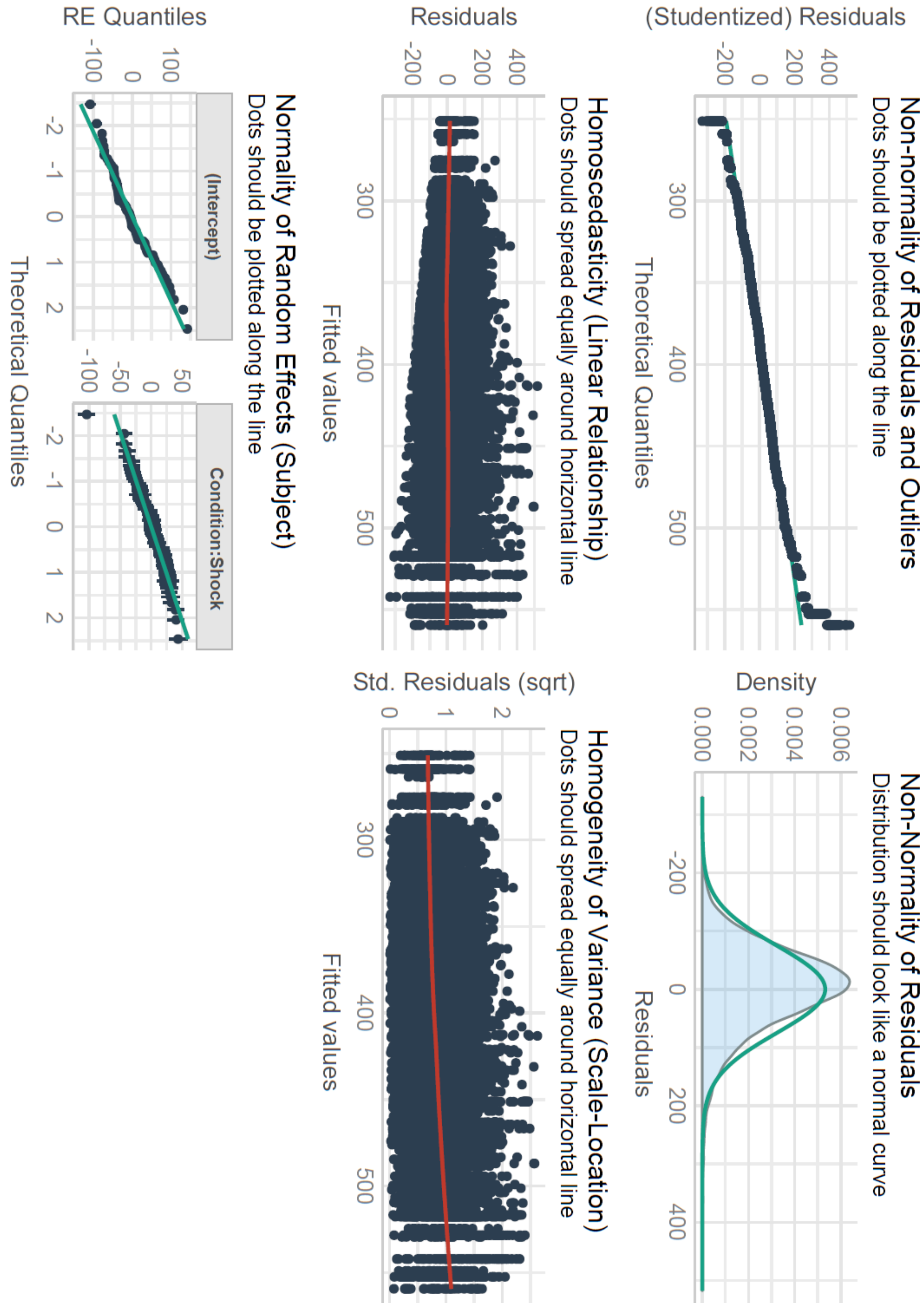
9.1. Appendix A: Example MLM f-like table for RT estimation of incongruent and congruent trials.

1a. Type III Analysis of Variance Table with Satterthwaite's method for RT estimation.

Predictors	*Mean Sq*	*NumDF*	*DenDF*	*F value*	*Pr(>F)*
Order	20	1	71	0.00	0.95
Trial Type	10774441	1	34972	1910.79	0.00
Block	9188	1	34973	1.63	0.20
Condition	37595	1	75	6.67	0.01
Trial Type*Block	169703	1	34971	30.10	0.00
Trial Type*Condition	63638	1	34980	11.29	0.00
Block*Condition	35656	1	34975	6.32	0.01
Trial Type*Block*Condition	2288	1	34972	0.41	0.52
Random Effects					
σ^2	5638.73				
$\tau_{00\ Subject}$	3032.27				
$\tau_{11 Subject.ConditionShock}$	662.87				
$\rho_{01\ Subject}$	-0.61				
ICC	0.31				
$N_{Subject}$	73				
Observations	35121				
Marginal R^2 / Conditional R^2	0.053 / 0.343				
Deviance	403584.687				
AIC	403578.386				
log-Likelihood	-201776.188				

Note: Mean Sq = Mean Square. NumDF= Numerator of DF; Den = denominator of DF.

9.2. Appendix B. Model diagnostics for RT estimation of incongruent and congruent trials.



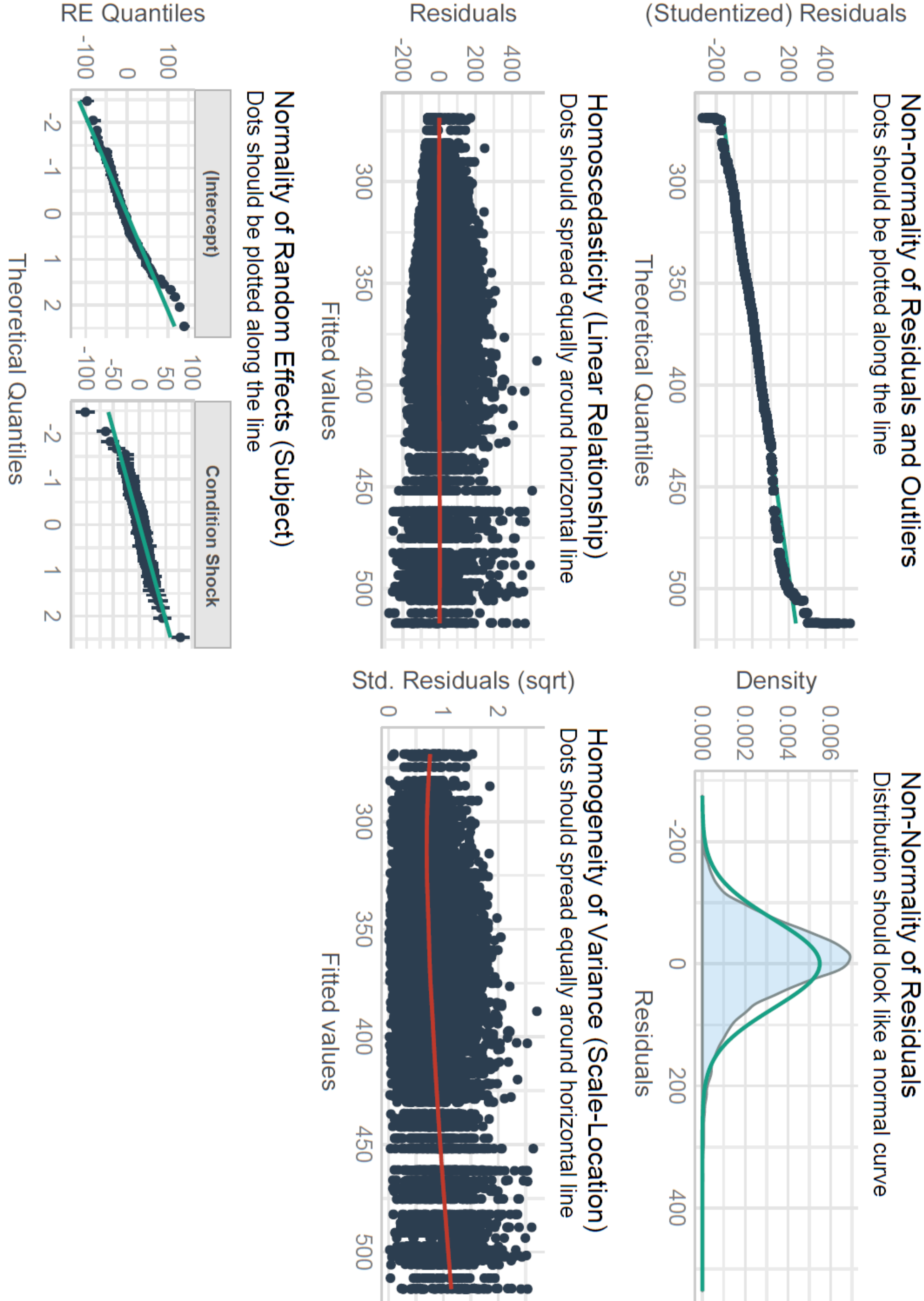
9.3. Appendix C: Example MLM f-like table for RT estimation of dist-Abs trials.

2a. Type III Analysis of Variance Table with Satterthwaite's method for RT estimation for Dist-Abs trials.

Predictors	*Mean Sq*	*NumDF*	*DenDF*	*F value*	*Pr(>F)*
Order	247	1	71	0.05	0.83
Block	378482	2	20381	71.00	0.00
Condition	26664	1	74	5.05	0.03
Block*Condition	41001	2	20382	7.69	0.00
Random Effects					
σ^2	5330.75				
$\tau_{00\ Subject}$	2368.79				
$\tau_{11 Subject.\ ConditionShock}$	690.92				
$\rho_{01\ Subject}$	-0.49				
ICC	0.28				
$N_{Subject}$	73				
Observations	20528				
Marginal R^2 / Conditional R^2	0.007 / 0.287				
Deviance	234906.226				
AIC	234900.648				
log-Likelihood	-117439.318				

Note: Mean Sq = Mean Square. NumDF= Numerator degrees of freedom; DenDF = denominator degrees of freedom; ICC = Intraclass correlation.

9.4. Appendix D: Model diagnostics for RT estimation of Dist-Abs trials.



Curriculum Vita

Salahadin (Sala) Lotfi

Website: https://github.com/salahlotfi
Twitter: @SalaLotfi
Email: Salahadin.lotfi@gmail.com

Future Position

Senior Biostatistician, Rogers Behavioral Health, Clinical Effectiveness & Research Center.

Education

Graduate:

Program: Ph.D. in Psychology, University of Wisconsin-Milwaukee (2020)
Dissertation: *Proactive and Reactive Cognitive Control under Threat of Unpredictable Shock: A Combined Eye-tracking and EEG Study Using Multilevel Modeling*
Advisor: Han-Joo Lee, Ph.D.

Program: M.A. in Psychology and Education of Exceptional Children, University of Tehran, Iran (2013)
Thesis: *The Effectiveness of Computerized Cognitive Training on Visual Spatial Working Memory Performance of Children with Reading Problems*
Advisor: Dr. Mohsen Shokoohi-Yekta.

Undergraduate:

Program: B.A. in Psychology, Shahid Beheshti University, Tehran, Iran (2010)
Project: *The comparison of Emotional Intelligence among Individuals with and without Hearing Impairment.*

Awards and Honors

- ✓ The 2020 UWM Distinguished Dissertation Fellowship Award.
- ✓ The 2019 UWM Graduate Student Excellence Fellowship Award.
- ✓ Society for Research in Psychopathology Travel Award Recipient, 2019.
- ✓ Award Recipient of the 25th Wisconsin Symposium on Emotion, 2019.
- ✓ Trainee Travel Scholarship, UT Austin Conference on Learning and Memory, 2017.
- ✓ UWM Graduate Students Travel Award, 2017.
- ✓ Chancellor's Graduate Student Award, University of Wisconsin-Milwaukee, 2014-2016.
- ✓ Summer Research Fellowship Award, Department of Psychology, UWM, 2016.
- ✓ Sigma Xi Grants-in-Aid of Research Award, 2015.

Research Experience

University of Wisconsin-Milwaukee, Anxiety Disorders Lab

- ✓ Student Principal Investigator (Jan 2018-2020)

Project 1: **State Anxiety Effects on Cognitive Control: A Multilevel Modeling of EEG & Eye-tracking data**

Duties: Designing a randomized control experiment, Programming a cognitive task via e-prime language to make communications with both EEG machine and Eye-tracking, developing online questionnaires (Qualtrics), writing EEG, eye-tracking and survey data analysis pipeline from scratch through R, Matlab, SAS, SPSS, supervising and train undergraduate research assistants, writing manuscript, conference presenting. Design advance multilevel data structure of EEG and survey data and implement MLM, Developed algorithm to classify and predict questionnaire data via machine learning methods.

Supervisors: Han-Joo Lee, Ph.D.

✓ Student Co-Principal Investigator with Richard Ward (Nov 2018-2020)

Project 2: **Examining Visual Memory Capacity under The threat of shock: Evidence from an EEG and Functional Near-Infrared Spectroscopy (fNIR) Study.**

Duties: Designing a randomized control experiment, setting and calibrating fNIR device, programming computerized cognitive tasks used with fNIR, creating statistical pipeline analysis for behavioral and the fNIR data through R, SAS, SPSS.

Supervisors: Han-Joo Lee, Ph.D.; Christine Larson, Ph.D.

✓ Student Principal Investigator (2015-2018)

Project 3: **Improving Attentional Control through Computerized Working Memory Training for Anxious Individuals.**

Duties: Designing a pseud-randomized experiment, setting and running EEG/ERP experiments, Designing and analyzing EEG/ERP data using Matlab, SAS and SPSS, modifying computerized cognitive tasks, supervising and train undergraduate research assistants, writing manuscript, conference presenting. Developed algorithm to classify and predict questionnaire data via machine learning methods,

Supervisors: Han-Joo Lee, Ph.D.; Christine Larson, Ph.D.

✓ Project Coordinator (2016-2018)

Project 4: **Computerized Working Memory Training for Veterans with Elevated Trauma-related Symptoms**

Duties: Programming the computerized task, Conduct structured clinical interviews using the MINI, coordinating and running assessment sessions, preprocessing computerized cognitive tasks and heart rate data, reviewing and writing relevant literature, manuscript writing.

Supervisors: Han-Joo Lee, Ph.D.; Sadie Larsen, Ph.D.; Christine Larson, Ph.D.

Atieh Neuroscience Center, Tehran, Iran

✓ Student Principal Investigator (2011-2013)

Project: **Effectiveness and Comparison between Computerized Cognitive Rehabilitation Training and Neurofeedback Training on Working Memory of Students with Attention problems: An ERP Study**.

Duties: Designing and running EEG/ERP experiments, analyzing EEG/ERP and behavioral data, supervising and train research assistants.

Supervisors: Reza Rostami, Ph.D.

<u>Publications</u> (Citations = 76, h-index = 7)

➢ Published Peer-Reviewed Papers

1. **Lotfi, S.**, Ward, R., Ayazi, M., Bennett, K., Larson, C. L., & Lee, H.-J. (2020). The Effects of Emotional Working Memory Training on Worry Symptoms and Error-Related Negativity of Individuals with High Trait Anxiety: A randomized Controlled Study. *Cognitive Therapy and Research (special issue).* https://doi.org/10.1007/s10608-020-10164-7
2. **Lotfi, S.,** Rostami, R., Shokoohi-Yekta, M.,..., & Lee, H-J., (2020). Effects of Computerized Cognitive Training for Children with Dyslexia: An ERP Study. *Journal of Neurolinguistics 55*, 100904.
3. Berlin, G., Mathew, A., **Lotfi, S.**, Harvey, A., Lee, H-J, (2020). Evaluating the effects of online tDCS with emotional n-back training on working memory and associated cognitive abilities. *NeuroRegulation*. 7(3), 129-129.
4. Ward, R., **Lotfi, S.**, Lee, H-J, Larson, C., (2020). State anxiety reduces working memory capacity but spares filtering efficiency. *Psychophysiology*. 57(10), e13625.
5. Larsen, S., **Lotfi, S.**, Bennett, K., Larson, C. L., Dean, C., & Lee, H.-J. (2019). A pilot randomized trial of a dual n-back emotional working memory training program for veteran with elevated PTSD symptoms. *Psychiatry Research. 275,* 26-268.
6. Ward, R., Miskovich, T., Stout, D., Bennet, K., **Lotfi, S.**, Larson, L., (2019). Reward-related Distractors and Working Memory Filtering. *Psychophysiology.56*, (10), 1-18.
7. Davine, T., Snorrason, I., Berlin, G., Harvey, A., **Lotfi, S.** & Lee, H.-J., (2018). Development of a picture-based measure for "Not Just Right" experiences associated with compulsive sorting, ordering, and arranging. *Cognitive Therapy and Research, 43* (2), 1-17.
8. Lee, H.-J., **Lotfi**, S. (2017). Mental Health Disorder. In Amy E. Wenzel (Eds.), *The Sage Encyclopedia of Abnormal Clinical Psychology.* Sage Publication.
9. Shouli, A. H. F., **Lotfi, S.,** & Arbabi, E. (2014). Brain plasticity in dyslexia after computer training: Spectral analysis based on statistical t-test. In *ICBME*. IEEE (pp. 161-166).
10. Shokoohi-Yekta, M., **Lotfi, S.,** Rostami, R., Arjmandnia, A.A., Motamed, N., & Sharifi, A., (2013). The effectiveness of computerized cognitive training on the working memory performance of dyslexic children**.** *Audiology, 23*(3) pp.46-56.
11. **Lotfi, S.**, Eizadi-Fard, R., Ayazi, M., & Agheli-Nejad, M., A. (2011). The Effect of Meichenbaum's Cognitive Behaviour Modification Therapy on Reduction of Test Anxiety Symptoms in High School Girls. *Procedia-Social and Behavioral Science.30*, 835-838.
12. Shokoohi–Yekta, M., Parand, A., Zamani, N., **Lotfi, S.** & Ayazi, M., (2011). Teaching problem-solving for parents: Effects on children's misbehavior. *Procedia-Social and Behavioral Science, 30, 163-166.*
13. Shokoohi–Yekta, M., Zamani, N., Parand, A., Ayazi, M. & **Lotfi, S.** (2011). Effects of anger management workshops on mothers of children with special needs. *Procedia-Social and Behavioral Science, 30, 159-162.*

➢ Manuscripts Under Editorial Review or Preparation

1. **Lotfi, S.,** Ward, R., Mathew, A., Shokoohi-Yekta, M.,..., & Lee, H-J., (2020). Limited Visual Working Memory Capacity in Children with Dyslexia: an ERP Study. *Scientific Studies of Reading.*

2. Ward, R., **Lotfi, S**., Stout, D., Mattson, S., Lee, H. J., & Larson, C. L. (Under Review). No differences in filtering efficiency for threatening and neutral words in attention and working memory. *Biological Psychology*.
3. Mathew, A., **Lotfi, S.**, Bennett, Larsen, S., Dean, C., Larson, C., & Lee, H.-J. (Under review). Association between Spatial Working Memory and Re-experiencing Symptoms in PTSD. *Journal of Behavior Therapy and Experimental Psychiatry*.
4. **Lotfi, S.**, Ward, R., Ayazi, M., Larson, C. L., & Lee, H.-J. (In Preparation). Effects of Contextual Manipulation Paradigm on Proactive versus Reactive Distraction Filtering: Evidence from a Combined EEG and Eye-tracking Study.
5. **Lotfi, S.**, Ward, R., Ayazi, M., Larson, C. L., & Lee, H.-J. (In Preparation). Temporal Dynamics of Stimulus Presentation on Flanker Congruency Proportion Effect and Cognitive Control: Eye-gaze and ERP Insights.

➢ Published Conference Presentations

1. **Lotfi, S.,** Rech, M, Ward, R., Larson, C. L. & Lee, H-J (2019). *State Anxiety and Cognitive Control: Evidence from a Combined Study of Shock Paradigm, Eye-tracking, and EEG.* Poster presented at the 33rd annual meeting of the Society for Research in Psychopathology. Buffalo, NY. ***(Travel Award Winner)***
2. **Lotfi, S.,** Ward, R., Larson, C. L. & Lee, H-J (2019). *Proactive versus Reactive Distraction Filtering under The threat of shock: EEG and Eye-tracking Study*. Poster presentation to be given at the 25th Wisconsin Symposium on Emotion. Madison, WI. ***(Travel Award Winner)***
3. **Lotfi, S.,** Rech, M, Ward, R., Larson, C. L. & Lee, H-J (2019). *Proactive versus Reactive Distraction Filtering under Threatening Conditions: Evidence from a Combined EEG and Eye-tracking Study*. Poster presented at the Society for Psychophysiological Research 59th annual convention. Washington, D.C.
4. Ward, R., Sallmann, H., Ginter, C., **Lotfi, S.**, Lee, H., & Larson, C. L. (2019). *The threat of shock-Induced Anxiety Reduces Working Memory Capacity*. Poster presented at the Society for Psychophysiological Research 59th annual convention. Washington, D.C.
5. **Lotfi, S.,** Burdis, B., Rech, M., et al, & Lee, H-J (2019). *Proactive versus Reactive Distraction Filtering: Evidence from a Combined EEG and Eye-tracking Study*. Poster presented at the Annual meeting of Society of Cognitive Neuroscience. San Francisco, CA.
6. Ward, R., Sallmann, H., Ginter, C., **Lotfi, S.,** Lee, H., & Larson C.L. (2019). *Reduced working memory capacity under threatening context.* Poster presentation to be given at the Annual meeting of Cognitive Neuroscience Society. San Francisco, CA.
7. **Lotfi, S.**, Bennett, K.P., Larsen, S.E., Larson, C.L., Dean, C., & Lee, H.-J., (2018) *Working Memory and Cognitive Control Performance among Veterans with Elevated PTSD Symptoms*. Poster presented at the 32nd annual meeting of the Society for Research in Psychopathology, Indianapolis, IN.
8. **Lotfi, S.**, Berlin, G., Ayazi, M., Larson, C., & Lee, H.-J., (2018) *Exploring Frontal Midline Theta Activity during a Thought Suppression Task in a Highly Trait-Anxious Sample*. Poster presented at the 52nd annual convention of Association of Behavioral and Cognitive Therapies, Washington, DC.
9. Bennett, K.P., **Lotfi, S.**, Dean, C., Larsen, S.E., Larson, C.L., & Lee, H.-J. (2018) *Avoidance and autonomic inflexibility in veterans with chronic PTSD symptoms.* Poster presented at the annual meeting of the Society for Research in Psychopathology, Indianapolis, IN.
10. Larsen, S.E., **Lotfi, S.**, Bennett, K.P., Larson, C.L., Dean, C., & Lee, H.-J., (2018) *Emotional Working Memory Training for Chronic PTSD: Effects on PTSD Symptoms and Memory*. Poster presented at the International Society for Traumatic Stress Studies Thirty-fourth Annual Meeting in Washington, DC.

11. **Lotfi, S.**, Ayazi, M., Bennett, K., Dommer, L., Mathew, A., Larson, C., & Lee, H.-J., (2018) *The Prefrontal Theta Activity during Thought Suppression compared to Thought Free Predicts Lower Working Memory and Higher Worry symptoms and Rumination in High Trait Anxiety*. Poster presented at 25th Annual Meeting of the Cognitive Neuroscience Society, Boston, MA.
12. Dommer, L., **Lotfi, S.**, Larson, C., & Lee, H.-J., (2018) *The Association Between Cognitive Interference, Anxiety, and Frontal Beta Brainwave Patterns*. Poster presented at the 10th Annual UWM Undergraduate Research Symposium, Milwaukee, WI.
13. Cavanaugh, S., Peterson, E., **Lotfi, S.**, Ayazi, M., Bennet, K., Larson, C., & Lee, H. (2016). *EEG Peak Frequency of Frontal-Midline Theta and its Association with the Interference Control in Individuals with High Trait Anxiety*. Poster presented at the MIDBRAIN Research Symposium in Neuroscience, University of St. Thomas. Minneapolis, MN.
14. Bennett, K., **Lotfi, S**., Larson, C., & Lee, H.-J., (2017) *Working Memory Training Does Not* Modulate Error-Related Negativity in Anxious *Individuals.* Poster presented at 57th Annual Meeting of the Society for Psychophysiological Research, Vienna, Austria.
15. **Lotfi, S.**, Ayazi, M., Peterson, E., Yaroch, M., Lehman, S., Larson, C., & Lee, H.-J (2017) *Emotional Working Memory Training Improves Filtering Efficiency and Worry Symptoms of Individuals with High Trait Anxiety*. Poster presented at UT Austin Conference on Learning and Memory, Austin, TX. ***(Travel Award Winner)***
16. **Lotfi, S.,**, Bennett, K., Ayazi, M., Peterson, E., Cavanaugh, S., Larson, C., & Lee, H.-J., (2017) *Inverse EEG Theta Peak Frequency Oscillation in Frontal- and Parietal-midlines Predicts Lower Cognitive Control and Working Memory in Individuals with High Trait Anxiety*. Poster presented at 24th Annual Meeting of the Cognitive Neuroscience Society, San Francisco, CA.
17. **Lotfi, S.,** Ayazi, M., Brooks, S., Cavanaugh, S., Bennet, K., Larson, C., & Lee, H. (2016). *Heightened negative affect may impair verbal but not visual working memory*. Poster presented at the AGSIP 18th Annual Research Symposium, Milwaukee, WI.
18. Shokoohi-Yekta, M., Mahmoudi, M., Bonab G., B., Zardkhaneh A., S. & **Lotfi, S.** (2013). *Designing an expert system to screen for autism: Investigating psychometric properties.* AWERProcedia Information Technology & Computer Science. [Online] 04, pp 1074-1078.
19. Shokoohi-Yekta, M., Mahmoudi, M., Bonab G., B & **Lotfi, S.** (2013). *Online expert system for screening autism: an item analysis. AWERProcedia Information Technology & Computer Science*. [Online] 04, pp 1069-1073.
20. *hokoohi-Yekta, M.,* ***Lotfi, S.,*** *Rostami, R.,* Yeganeh, N., Lou, K., Y. & Habibnezhad, M. *(2013) Brain Training by BrainWare® Safari: The Transfer Effects on the Visual Spatial Working Memory of Students with Reading Problems.* AWERProcedia Information Technology and Computer Sciences. [Online] 04, pp 1046-1052.
21. Shokoohi–Yekta, M., Parand, A., Zamani, N., Ayazi, M. and **Lotfi, S**. (2011) *Efficacy of Teaching New Parenting Strategies based on Problem Solving Approach*. Procedia-Social and Behavioral Science, 30, 167-170.
22. Shokoohi–Yekta, M., Zamani, N., **Lotfi, S.**, & Ayazi, M. (2011) E*ffects of Cognitive-Behavioral Instructions on Anger Control in Teachers of Students with Mental Retardation: A Follow-Up Study*. Paper presented at the 7th international congress in cognitive psychotherapy, Istanbul, Turkey (peer-reviewed).
23. Shokoohi–Yekta, M., Zamani, N., Parand, A., Akbari, S., **Lotfi, S.**, & Ayazi, M. (2011) *Effectiveness of Anger Management Training on Emotional Self-Regulation of Parents*. Paper presented at the 7th international congress in cognitive psychotherapy, Istanbul, Turkey (peer-reviewed).
24. **Lotfi, S.,** & Ayazi, M., (2011) *The comparison of Emotional Intelligence of Individuals with and without hearing impairment.* Paper presented at the 2nd World Conference on Psychology, Counseling and Guidance, Antalya, Turkey. , 25-29 May 2011. (peer-reviewed).

Clinical Experience

- ✓ Clinician and Supervisor of Cognitive Training Section *(Atieh Neuroscience Center, Tehran, Iran, 2012-14)*
    - Ran assessment and therapy sessions, oversaw the therapeutic goals, monitored therapists, evaluated patients' progress and provided feedback, lunched neurofeedback projects.
- ✓ Group psychotherapist with adolescents *(Atieh Neuroscience Center, Tehran, Iran, 2011-12)*
    - *Ran weekly group therapy for adolescents with emotional psychological problems.*

Teaching Experience

The Department of Psychology, University of Wisconsin-Milwaukee, USA

✓ Position: Teaching Assistant (in-class experience)
Semesters: Fall 2015, Spring and Fall 2017, Spring 2018
Course: **Psychological Statistics**, **Introduction to Psychology**
Instructor: Han-Joo Lee, Ph.D., Karyn Frick, PhD., Jenny Kunz, PhD.
Duties: Teaching two lab and discussion sections (4 hours weekly), Weekly instructional meeting with students, setting up the online quizzes and exams, managing the online course materials, in person mentoring sessions with students

✓ Position: Teaching Assistant (online class experience)
Semesters: Fall 2018, Spring & Fall 2019
Course: **Research Methods in Psychology**; Perceptual Processes; Psychology 101;
Duties: Revising course materials, tutoring students, providing feedback for APA style research reports, in person mentoring sessions with students, grading exams.

✓Position: Project Contributor
Semesters: Spring and Summer 2017
Project: Level 3 Open textbook and Open Educational Resource Adoption Project for Introduction to Psychology
Project Leader: Han-Joo Lee, Ph.D.
Duties: Revising course materials; organization and design of PSY101; developing centralized, shared resources to improve the overall quality; designing real-time polling-based PPT quiz for the entire book; developing shared D2L space with integrated online quizzes and questions banks; organizing a uniformed syllabus, lecture slides and materials for in-class activities.

The Department of Psychology and Exceptional Children, University of Tehran, Iran

✓ Position: Class coordinator
Semesters: Fall 2011 and Spring 2011
Course: Psychological Assessment I, Psychological Assessment II.
Instructor: Mohsen Shokoohi-Yehta, Ph.D
Duties: Attending lectures, conducting twice- weekly reviews and discussion sessions, checking students class works, grading and reporting to the instructor

Research Mentoring Experience

UWM, Anxiety Disorders Lab, 2015-Present

- ✓ Trained undergraduate RAs to administer IRB protocols, program E-prime tasks, collect EEG data, pre-process Excel and EEG data using Matlab and R software packages, and guide them to write scientific reports.
- ✓ Supervised and helped following RAs to present poster presentations at regional and national scientific conferences: Shannon Cavanaugh, Stephanie Brook, Erin Peterson, Lukas Dommer-Kush, Mary Yaroch, Sarah Lehman, Caed Burdis, Madeline Koch, Tien Kolodziej, Rin Nguyen, Ashna Pandya.
  - MIDBRAIN Research Symposium in Neuroscience, University of St. Thomas, MN. 2016
  - UWM AGSIP Annual Symposium, University of Wisconsin-Milwaukee, 2016-2019.
  - UWM Undergraduate Research Symposium, University of Wisconsin-Milwaukee, 2016-2019.
- ✓ Supervised and supported four undergraduate RAs to receive the UWM Support for Undergraduate Research Fellowship (SURF): Shannon Cavanagh (2016), Lukas Dommer-Koch (2017), Madeline Rich (2018), Tien Kolodziej (2020).

Administrative Experience

- ✓ Elected as outstanding head of "Students Scientific Associations of Shahid Beheshti University", 2008.
- ✓ Founder and head of "Students Scientific Association of Psychology" at Shahid Beheshti University for two years, 2006 to 2008.
- ✓ Secretary of "*the 2nd Scientific National Conference of Iranian Students of Psychology"*, Tehran, Iran. April 2010.
- ✓ Director of charge and editor in chief of "Student Journal of Psychological Studies", in SBU, Iran, 2006-2010.
- ✓ Member of "Supervisory Committee of the Student Journals" of the SBU, 2008-2009.
- ✓ Association of Clinical and Cognitive Neuroscience, UWM, USA. President: May 2017-Present
- ✓ Students Scientific Associations, Shahid Beheshti University (SBU), Iran. Founder and President: May 2006-May 2009
- ✓ Student Journal of Psychological Studies, SBU, Iran., Editor-in-chief: March 2005-May 2009.

Statistical and Data Science Skills

- ✓ Data Wrangling Methods for large data *(cleaning, aggregation, exploration, visualization; R/Python)*
- ✓ Multilevel/Hieratical Linear Modeling *(multilevel longitudinal structures of self-report surveys with missing data, computerized assessments and training of large datasets; R/SAS/SPSS)*
- ✓ Multivariate Imputation by Chained Equations for handling missing data (R, package MICE).
- ✓ Applied Multivariate Statistical & Discriminant Analysis *(CFA & PCA of dimension reduction techniques to extract best features of large data; R/SAS)*
- ✓ Advance Regression Methods *(Regularization-Lasso, Logistic Regression; R)*
- ✓ Bayesian Analysis (R)
- ✓ Random Forest and Boosting, Decision Trees, Neural Networks, k-Nearest Neighbors, Support Vector Machine and Gradient Boosting *(training and building predictive classifiers models for surveys and psychological assessment data; R caret)*

Software Packages

- ✓ R *(advance; tidyvers, lme4, nlme, ggplot2, caret, R markdown, emmeans, magrittr, many more)*
- ✓ Python Programming for big medical data (SEER and CDC datasets)
- ✓ SAS *(proc mixed, proc glm, proc lm)*
- ✓ Matlab *(advance; EEGlab, ERPlab, FieldTrip)*
- ✓ E-prime & SPSS *(advance)*
- ✓ Linux, High Performance Computing *(basics)*

References

Han-Joo Lee, Ph.D.

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