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Differential Neural Correlates Underlying Different Cognitive Control Strategies and their Relationship with the Barratt Impulsiveness Scale

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Differential Neural Correlates Underlying Different Cognitive Control Strategies and their Relationship with the Barratt Impulsiveness Scale

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Abstract

Impulsivity is defined as a rapid unplanned action to a stimulus, where the person does not consider the consequences of their actions (Moeller et al., 2001). Various measurement techniques exist in the study of impulsivity and include self-report, behavioral and physiological measures. This breadth of measurement techniques affords researchers the opportunity to understand what is likely a multifaceted nature of this construct. Previous literature shows mixed results between the relationship of the three measures. The present study seeks to add clarity between the three different modalities of measuring impulsivity. To address this relationship, an undergraduate sample (n = 171) completed three behavioral tasks, AX-CPT, Go/Nogo, and a modified Flanker while physiological data was collected with electroencephalography. The participants also completed the Barratt Impulsiveness scale, a self-report measure. Higher impulsivity was associated with worse accuracy and a smaller N2 for Nogo trials than individuals with lower impulsivity. Higher impulsivity was also associated with worse accuracy for A-Y trials and a reduced amplitude for B-X trials.

Introduction

Moment-to-moment, we all apply cognitive control strategies to navigate our sophisticated lives and deficits in cognitive control can lead to impulsivity (Shiels & Hawk Jr, 2010). Impulsivity is defined as a rapid unplanned action to a stimulus, where the person does not consider the consequences of their actions (Moeller et al., 2001). The fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V; American Psychiatric Association, 2013) incudes impulsivity as criteria for multiple pathological disorders (Moller et al., 2001.) These disorders include Attention-Deficit/Hyperactivity Disorder (ADHD), Bipolar Disorder, Borderline Personality Disorder, and substance use disorders. The Center for Disease Control (CDC) states that the years from 1999 – 2019, nearly 500,000 people in the United States have died from an Opioid overdose and the year-to-year trend continually rises. Many adults who abuse substances began using in their teenage years (CDC). Impulsivity has been shown to be a predictor of addictive behaviors (Garavan, 2011).

Within the extant literature, there are many ways of measuring impulsivity, both via self-report questionnaires and behaviorally. However, the Barratt Impulsiveness Scale (BIS, Patton et al., 1995) seems to be one of the most frequently used. As is reviewed by (Stanford, et al., 2009) the BIS is both reliable and valid. However, the BIS cannot shed light on the neural deficits underlying impulsivity.

A considerable body of literature has correlated impulsivity, using the BIS, with various event-related potentials (ERPs), such as the N2 (Kam et al., 2012, Knežević, 2018, Omura, & Kusumoto, 2015), a mediofrontal negative deflection that occurs roughly 200 to 400 ms after an event that requires aspects of cognitive control, such as

inhibition of action (Lamm & Lewis, 2010). Omura and Kusumoto, (2015) utilized a continuous performance task (CPT), in a Go/Nogo format, to investigate sex differences of impulsivity in a non-clinical sample. The study explored gender and self-reported impulsivity (including the BIS) differences in ERP amplitude, including the N2. They found a significant correlation between the amplitude of the N2, on No/Go trials, and the BIS-attentional subscale in males. Furthermore, Kam et al., (2012) investigated the relationship between executive functions and the BIS, in a non-clinical sample using AX-CPT to assess cognitive control. They found a significant correlation between the N2 and the BIS-motor subscale. As the BIS-motor subscale increased, N2 amplitude decreased (more negative) on all conditions.

Utilizing a Go/Nogo task, Zhou et al., (2010) investigated inhibitory control of individuals with pathological internet use (PIU). Compared to controls, PIUs total BIS scores and subscale scores were higher and PIUs showed reduced amplitude in the N2. There were no significant correlations between BIS scores and the N2. Also utilizing a Go/Nogo task, Knežević (2018) aimed to assess impulsivity differences between males and females, using self-report, behavioral measures, and electrophysiological recording. In a non-clinical sample, there was a significant correlation for an early sensory ERP, but showed no other significant correlation, including no relationship between the BIS and the N2. In fact, women rated themselves higher in impulsivity using the BIS, but men displayed higher impulsivity and showed larger N2 amplitudes, creating conflicting results between the two measures. The author suggests that each measure may be measuring different underlying constructs. In short, the nature of the relationship between impulsivity, measured via the BIS, and N2 amplitudes is still unclear. Some of the

inconsistency may be due to the tasks used to elicit N2 activation, for example the AX-CPT and the Go/Nogo task. Thus, the proposed project will examine the link between impulsivity, as measured via the BIS, and N2 amplitudes, elicited by the same participants playing three different tasks: the AX-CPT, the Go/Nogo, and a modified Flanker task.

Based on previous literature, this study hypothesizes that there will be a significant correlation between the BIS and the AX-CPT task, while not showing significance between the BIS and the Go/Nogo task. Additionally, due to a lack of literature between the BIS and the modified version of the Flanker task used in the current study, this analysis will be exploratory.

METHOD

Participants

The final sample for this study included 171 undergraduate students (81 males, 90 females) and were recruited from the University of Arkansas general psychology course. The mean age was 19.42 years (*SD* = 2.50, range = 18-47). All participants were English speaking. Criteria for exclusion from participating in the study, were current psychiatric diagnosis, current use of psychoactive medication, and uncorrected visual impairments. We prescreened for these through the University of Arkansas Sona System. After data collection, participants were excluded from analyses if any of the task conditions contained less than 10 correct artifact free trials (anything less created too low of a signal-to-noise ratio for ERP analyses) or had low accuracy in any of the conditions. For AX-CPT and Go/Nogo tasks, participants with less than 20% accuracy were removed.

For the hybrid Flanker Global/Local task, participants with less than 40% accuracy were removed. Each of these cutoffs excluded participants greater than about two standard deviations from the mean accuracy. All students were given course credit for their participation. Ethical approval for the study was obtained from the University of Arkansas' Institutional Review Board (1708026820).

Procedure

The procedure followed what was published in Rawls et al. 2018 and Long 2020 (dissertation). Participants were first introduced to the experimental environment and written informed consent was obtained. Participants then completed a battery of questionnaires while seated in the testing room. After the first set of questionnaires, participants were seated 67 cm in front of a computer monitor and the electrode sensor net was applied to their head. They then completed two practice blocks for each of three behavioral tasks to ensure they understood the task procedure. If the participants indicated they still did not understand, then the practice blocks were repeated. These three tasks were broken up into roughly 50 trial long blocks that vary pseudo-randomly in presentation order (but all participants receive the same trial order) and after each block participants took a break before beginning the next block. After completing all the task blocks, the electrode sensor net was removed, and a second set of questionnaires was completed, including the BIS. Following this second set, participants completed a Competitive Reaction Time (CRT) Task based on the Taylor Aggression Paradigm (which was not analyzed for this project and therefore will not be discussed) and upon completion filled out a third and final set of questionnaires. The entire study session on average took four hours to complete.

Measures

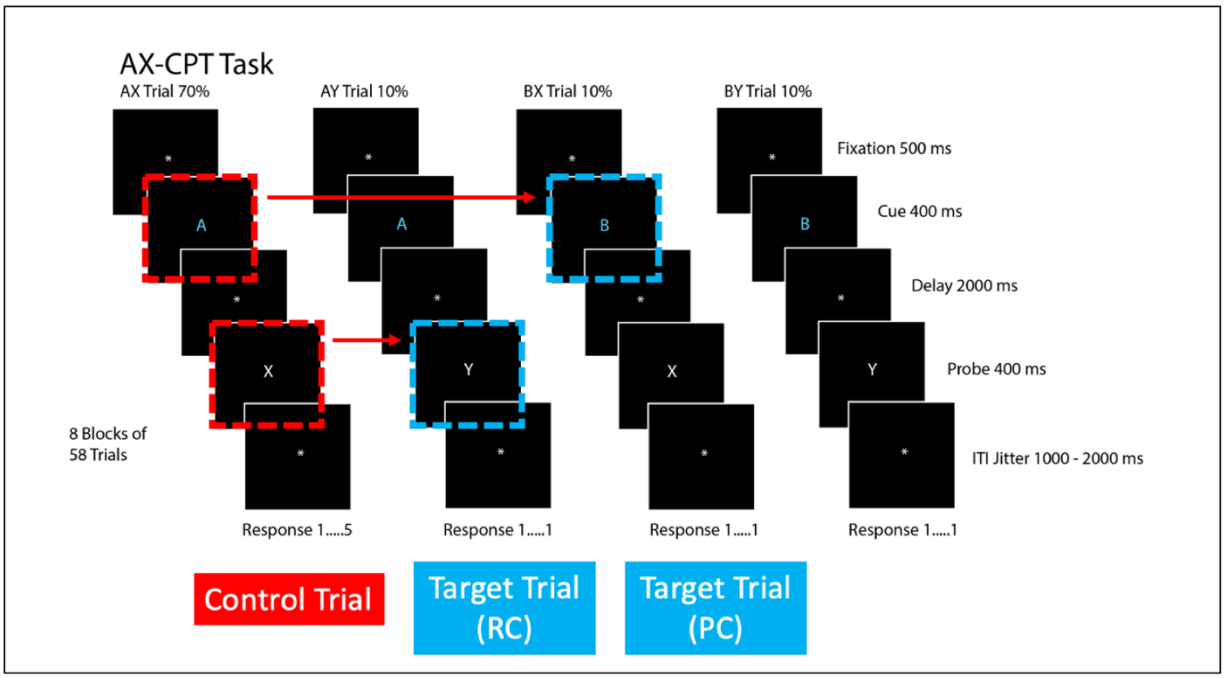
BIS-11. The *Barratt Impulsiveness Scale* (Patton et al., 1995) measures impulsivity by a thirty-item, self-report measure. The BIS-11 can be broken down into three subcategories that include motor impulsiveness (MI), non-planning impulsiveness (NPI), and cognitive impulsiveness (CI). Impulsivity is reported by a four-point scale, ranging from rarely to always. However, for the current project, only the overall BIS score was used. The BIS-11 includes such questions as, "I often have extraneous thoughts when thinking" and "I make-up my mind quickly."

AX-CPT. The Expectancy "AX" continuous performance task (AX-CPT; MacDonald and Carter, 2003) was used to assess proactive and reactive control. In this task, pairs of letters were presented, one following the other. The first letter (A or B) served as the cue and the second letter (X or Y) served as the probe. There were four trial types within this task, A-X, B-X, A-Y, and B-Y. Participants were told to press the first button on a five-button box as soon as they saw the first letter (the cue) on the screen. Then once they saw the second letter, the probe, they pressed either the first button or the fifth button as fast as they could. If they saw the target letter pair, A-X, they were instructed to press the first button and then the fifth button. But, if they saw any other pair of letters (B-X, A-Y, or B-Y) they were instructed to press the first button and then the first button again. Two practice blocks of 10 trials were presented before the task began. The practice blocks for this task included error feedback (a red dash appeared at fixation) following each trial if participants entered the wrong response or a response was too slow. The task consisted of eight blocks and each block contained 58 trials. Within each block, 70% of the trials contained A-X pairs, with the other three pairs equally appearing

on 10% of the trials to make up the other 30% of trials within the block. Order of presentation of these pairs was pseudo-randomized within blocks. Since the A-X pairs were presented the majority of the time, this requires participants to use specific cognitive strategies to respond appropriately during the other pairs of letters. During the B-X trials, participants had to maintain the memory of the B cue in order to respond correctly to the X probe. During A-Y trials, participants were primed with an A cue and had to adapt to the presentation of the Y probe when they expected an X probe.

All stimuli were presented on a 17-in monitor using E-prime Software (Psychology Software Tools, Inc.; Schneider, Eschman, & Zuccolotto, 2002). Stimuli were shown on a black screen. Each trial started with a fixation screen lasting 500 ms followed by the cue, which was displayed for 400 ms. After the cue, a delay fixation screen was presented for 2000 ms, followed by the probe, which was displayed for 400 ms. A fixation screen was displayed for an inter-trial interval that was jittered between 1000 – 2000 ms while participants waited for the next trial to begin. This timing variation ensures a variation in the phase oscillation upon which a stimulus falls from trial-to-trial to accurately capture event-related potentials. Cue and probe letters were presented in 60-point size uppercase bold Courier New font, with cue letters presented in blue font and probe letters presented in white font to help participants remember the letter order (see Figure 1).

Figure 1
Task diagram of the AX-CPT task



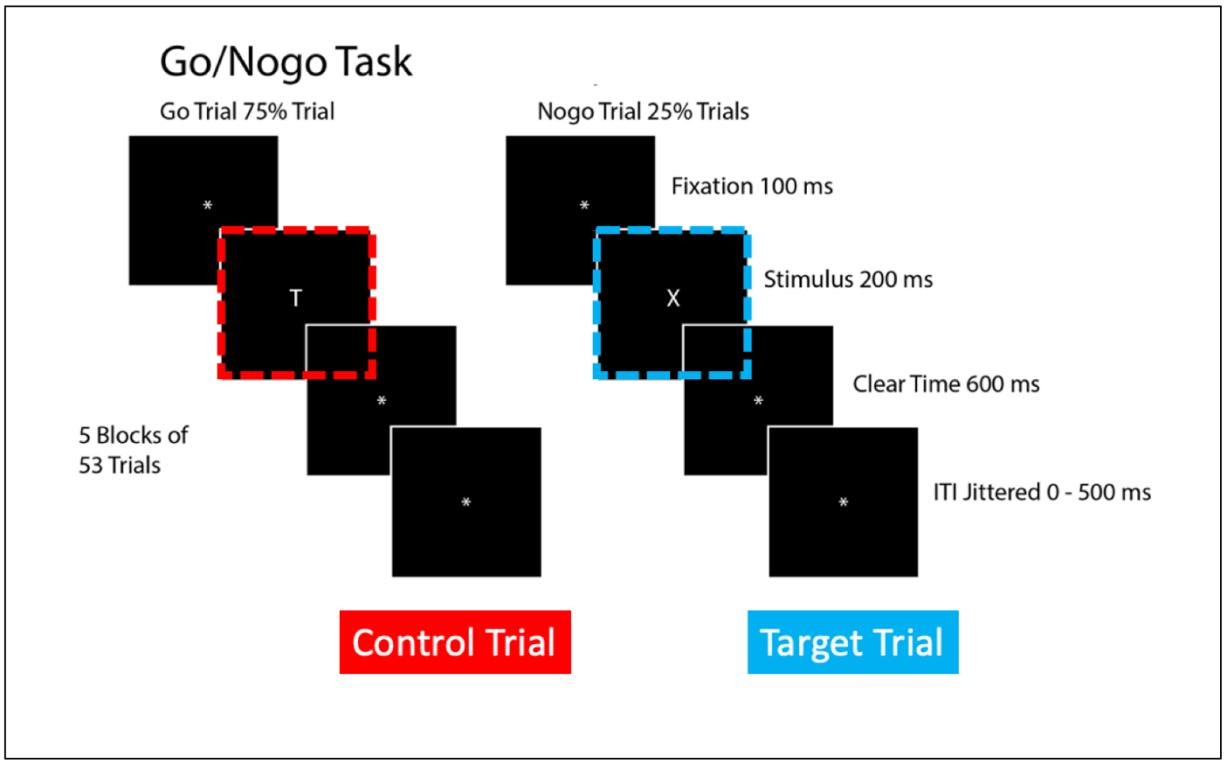
Note. The dashed boxes indicate the time-locked stimuli used for ERP analyses (note: the dashed boxes are for demonstration purposes; they were not shown in the task). The target condition stimuli are shown in blue and the control condition stimuli are shown in red.

Go/Nogo Task. The task was adapted from one used by Garavan et al., (1999). All stimuli were displayed using E-prime software as described in the section above. On each trial a white letter stimulus was presented at the center of the screen. Participants were told to respond on the button box as quickly and accurately as possible to each letter (Go stimuli) except if the letter that appeared was an "X" (Nogo stimulus), in which case they were told not to respond. Before the task began, participants completed one practice block of 10 trials.

The task consisted of five blocks of 53 trials each, where 75% of trials in each block contained Go stimuli and 25% of trials in each block contained Nogo stimuli. The order of these trial types was pseudo-randomized within blocks. Each trial began with a fixation screen that lasted 100 ms, followed by the stimulus, which displayed for 200 ms.

A fixation screen then appeared for 600 ms, while participants responded and then an inter-trial interval jittered from 0-500 ms (see Figure 2).

Figure 2
Task diagram of the Go/Nogo task



Note. The dashed boxes indicate the time-locked stimuli used for ERP analyses (note: the dashed boxes are for demonstration purposes; they were not shown in the task). The target condition stimuli are shown in blue and the control condition stimuli are shown in red.

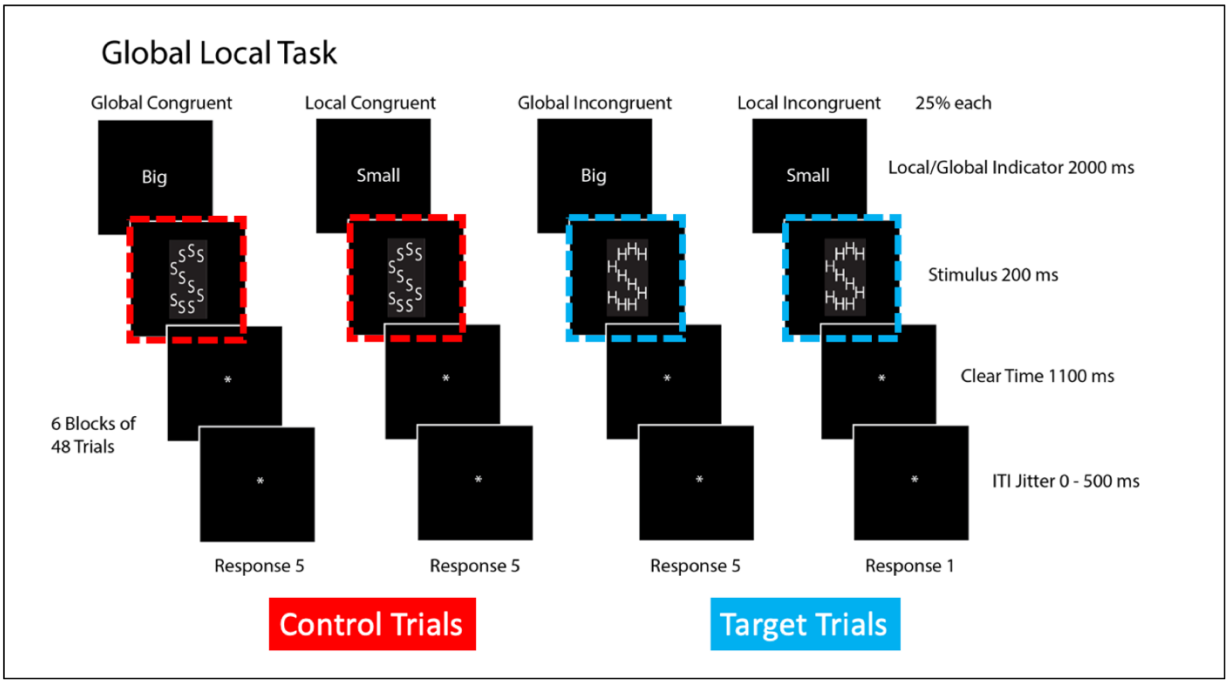
Hybrid Flanker Global/Local Task. This task was adapted from Navon (1977) and Eriksen & Eriksen (1974). We used this hybrid task because previous studies from our lab indicated that the canonical Flanker task may not be difficult enough in undergraduate samples to evoke the standard congruent – incongruent difference. During the task instructions, participants were instructed to respond with the first button on the button box if they saw stimuli containing “H”s or the fifth button of the button box if they saw stimuli containing “S”s. At the beginning of every trial, participants were first cued by seeing the word “Big” (global cue) or “Small” (local cue). Following the cue, each

trial contained either a congruent stimulus where both the global and local information led to the same response (e.g. a global H made of local Hs or a global S made of local Ss) or an incongruent stimulus where the global and local information led to a different response (e.g. a global H made of local Ss or a global S made of local Hs). Therefore, on congruent trials, the response was the same regardless of the cue. However, on incongruent trials the cue indicated to which information (global or local) participants were required to respond. Before the task began, participants completed two practice blocks of the task. The only difference in the practice blocks and the actual task was that the congruent and incongruent stimuli were displayed longer in the practice, so that participants could make sure they saw the global and local differences in the stimuli.

This task contained six blocks of 48 trials each. All four trial types (global congruent, local congruent, global incongruent, and local incongruent) were presented equally (25% of trials) within each block. The order of these trial types was pseudo-randomized within blocks. Each trial began with a global/local cue, which was displayed for 2000 ms. Then, the letter stimulus was displayed for 200 ms followed by a fixation screen that appeared for 1100 ms. Finally, an inter-trial interval fixation screen was jittered for 0-500 ms. Participants were instructed to respond as quickly and accurately as possible. All stimuli were presented using E-prime software as described in the AX-CPT section. The letter stimuli were displayed as white capital letters in Arial font (see Figure 3).

Figure 3

Task diagram of the modified hybrid Flanker Global/Local task



Note. The dashed boxes indicate the time-locked stimuli used for ERP analyses (note: the dashed boxes are for demonstration purposes; they were not shown in the task). The target condition stimuli are shown in blue and the control condition stimuli are shown in red.

EEG Data Collection and Processing

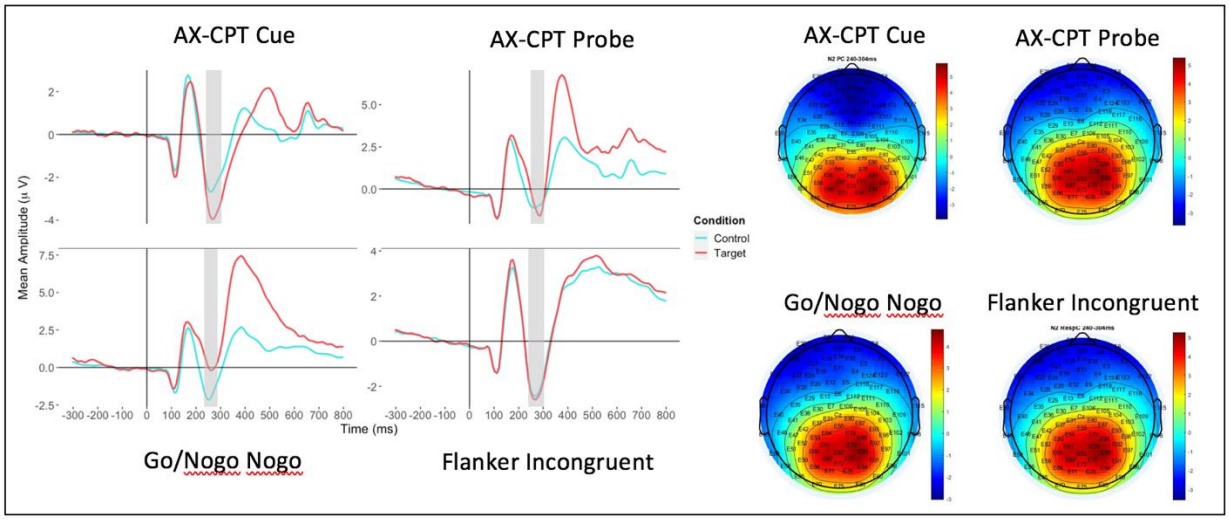
EEG data collection procedures were consistent with Lamm et al., (2013). EEG data was recorded using a 128-channel Geodesic Sensor Net and sampled at 1000 Hz using EGI software (Net Station; Electrical Geodesic, Inc., Eugene OR). Data acquisition only began after all EEG channel impedances were reduced to below 50 kΩ. During recording, all channels were referenced to Cz, but during data processing all channels were re-referenced using an average reference.

All EEG data were pre-processed in MATLAB's processing toolbox EEGLAB (Delorme & Makeig, 2004), using a pipeline developed by Dr. Eric Rawls. The data were bandpass filtered from 0.1 – 35 Hz using a zero-phase Hamming windowed-sinc FIR filter and downsampled to 125 Hz. EEG channels were removed and later interpolated if

the joint probability of that channel's data and all channel data exceeded four standard deviations from the mean. Then the data were segmented from -300 – 900 ms and stimulus-locked around each of the target stimuli associated with the cognitive strategies as well as the appropriate control condition stimuli. Consistent with the literature, we time-locked to the B of B-X trials, Y of AY trials (both from the AX-CPT), Nogo trials of the Go/Nogo task, and incongruent trials of the modified flanker task. Each segment was baseline corrected across the entire segment by mean-centering. Infomax ICA was run on this cleaned dataset using *runica* (Makeig et al., 1997) and using the ADJUST plugin (Mognon et al., 2011) to identify and remove artifactual components containing eye blinks, eye movements, and other stereotyped sources of motion artifacts. The cleaned segments were then examined for any further artifacts (such as fast transits) and were rejected with a threshold of ±140 μV. Finally, all removed channels were interpolated using spherical interpolation and all segments were averaged referenced. The N2 component means were only extracted from correct trials. Grand average waveforms were created for each self-regulatory strategy (averaged across the target conditions and control conditions to decrease selection bias) to select the N2 component time window (with 0 ms indicating stimulus onset; Figure 4). Then scalp distributions were created for all 128 electrodes to ascertain for which electrode the N2 component was maximal (Figure 4). Typically, the N2 is extracted from electrode FCz, so that electrode was chosen to align with the literature.

Figure 4

Grand averaged waveforms for the N2 for each strategy



Note. For visualization purposes, the target condition is shown in red and the control condition is shown in blue. Each N2 time window (shown in gray) was examined at the electrode where it showed maximum amplitude based on the scalp topography (FCz = electrode 6).

Data Analyses

We conducted multiple linear regression analyses, in which the target N2 or target accuracy data was the dependent variable. In step 1, we entered all nuisance variables. For target N2 analyses the nuisance variables were age, gender, target trial count, and control N2. For target accuracy analyses the nuisance variables were age, gender, and control accuracy. In step 2, we entered the BIS impulsivity score. We also assessed the relationship between target N2 and target performance accuracy for all three tasks using linear regression analyses. Again, age, gender, target trial count, and control N2 were entered as nuisance variables in step 1. In step 2, we entered target performance accuracy. Target N2 was the dependent measure.

RESULTS

Target Performance Accuracy and Target N2 Amplitudes

Results for the Go/Nogo task showed that worse performance accuracy was associated with smaller (less negative) Nogo N2 amplitudes, $\beta = -.225$, $t(170) = -2.24$, $p = .03$, and that performance accuracy predicted N2 amplitude over-and-above all nuisance variables, $\Delta R^2 = .017$, $F(1, 165) = 5.00$, $p = .03$. However, no such association was found for the AX-CPT or the modified Flanker task, $\beta = .006$, $t(170) = .113$, $p = .91$; $\beta = .065$, $t(170) = .558$, $p = .58$; $\beta = .011$, $t(170) = .365$, $p = .72$

BIS and Target Performance Accuracy

Results for Nogo trials showed that higher impulsivity was associated with worse performance accuracy, $\beta = -.138$, $t(171) = -1.94$, $p = .05$, over-and-above all nuisance variables, $\Delta R^2 = .019$, $F(1, 166) = 3.78$, $p = .05$. Furthermore, AX-CPT AY probes showed that higher impulsivity was associated with worse performance accuracy, $\beta = -.142$, $t(171) = -2.06$, $p = .04$, over-and-above all nuisance variables, $\Delta R^2 = .019$, $F(1, 166) = 4.24$, $p = .04$. No such effect was found for either AX-CPT BX cues or Flanker incongruent trials, $\beta = .019$, $t(171) = .29$, $p = .77$; $\beta = -.022$, $t(171) = -.41$, $p = .68$.

BIS and Target N2 Amplitudes

For Nogo trials, results revealed that higher impulsivity was associated with smaller Nogo N2 amplitude, $\beta = .117$, $t(170) = 1.95$, $p = .05$, over-and-above all nuisance variables, $\Delta R^2 = .013$, $F(1, 165) = 3.81$, $p = .05$. For AX-CPT BX cues, results revealed that higher impulsivity was also associated with smaller N2 amplitude, $\beta = .100$, $t(170) = 2.02$, $p = .05$, over-and-above all nuisance variables, $\Delta R^2 = .01$, $F(1, 165) = 4.07$, $p = .05$. However, for both AX-CPT AY probes and Flanker incongruent trials no significant

associations were found between N2 and BIS, β = .010, t(170) = .16, *p* = .88 and β = .013, t(170) = .41, *p* = .68, respectively. Thus, for cognitive control measured via the Go/Nogo task and the AX-CPT task (for cues), higher impulsivity was associated with smaller (less negative) N2 amplitudes.

Discussion

The following study aimed to add clarity to the previous literature that examines impulsivity by investigating the relationship between BIS and the N2 using three different cognitive tasks, the AX-CPT, Go/Nogo, and a modified Flanker. Higher impulsivity was associated with a smaller N2 for Nogo trials and BX cues. Although previous literature has found a relationship between the BIS and the N2, the studies reviewed in the introduction present different relationships than the current study. Kam et al., (2012) showed higher MI was associated with a larger N2 for all trials in the AX-CPT, while Omura and Kusomoto (2015) found higher AI was associated with a smaller Nogo-N2 for males. There are also multiple studies that show no relationship between N2 amplitudes and the BIS (Zhou et al., 2010, & Knežević, 2018).

Thus, the relationship between the BIS and N2 amplitudes, as well as the corresponding behavioral indexes (reaction time and performance accuracy) vary across multiple studies. Currently, it is unclear as to the cause of these differing results. While the BIS is a standard measure across all studies, the N2 is measured in relation to the behavioral task presented; thus, the differential results may be in part due to the context of the different tasks used. Omura and Kusomoto (2015) utilized the AX-CPT and presented it in the manner of a Go/Nogo. However, the AX-CPT utilized by Kam et al.,

(2012) was more similar to the task in the present study, the designed probe was either X or another letter, besides A, B, or K. The Go/Nogo utilized by Knežević, (2018) consisted of the letter X and Y. Go trials consisted of Y-X combinations, while Nogo trials were X-X or Y-Y. The large variations in behavioral tasks could elicit different cognitive control strategies.

The AX-CPT is generally used to assess reactive and proactive control (Braver, 2012), while the Go/Nogo is generally used to assess inhibitory control (Durston et al., 2002). Proactive control is a mechanism that allows for the active maintenance of goal-relevant information to drive behavior, while reactive control is a mechanism that incorporates last minute information to change a behavioral response (Braver, 2012). Inhibitory control is a mechanism that allows an individual to suppress relevant information and behaviors (Durston et al., 2002). The differential response pattern and event timing within each of the tasks might require slightly different cognitive processes. For example, the AX-CPT utilized by Omura and Kusomoto (2015) was in a Go/Nogo format and would not require the same cognitive control strategies as a traditional AX-CPT.

Literature has linked the recruitment of different patterns of neural activation to various cognitive-control strategies. Gonthier et al., (2016) investigated the Dual Mechanisms of Control (DMC) framework by manipulating the AX-CPT by inserting a Nogo feature. The authors suggest that proactive control activates the Lateral Prefrontal Cortex, while reactive control actives more of a frontoparietal network. The study also revealed that both mechanisms could possibly be recruited at the same time, preferentially using one or the other, or using neither. The Go/Nogo task requires

inhibition of a response and has been shown to elicit inhibitory control, which activates the anterior cingulate gyrus, caudate nucleus, and inferior frontal gyrus (Durston et al., 2002). Thus, the N2 would have a different morphology in each context and therefore a differential relationship with impulsivity.

There are some limitations that should be addressed. First, the sample consisted of an undergraduate population. Undergraduate samples may be too homogeneous to generalize to the general population, including age constraints. This may also have been true of our sample. Utilizing an undergraduate sample helped with recruiting a large sample; however, our results may have been limited when trying to apply the findings to other more heterogenous groups. Second, the sample excluded participants with a current psychiatric disorder, resulting in a non-clinical sample. Future studies would benefit from a less homogenous sample that include clinical groups to add external validity to the results.

Conclusion

The current study sought to add clarity to the literature concerning the relationship between self-report, behavioral, and physiological measures. Although there are significant findings presented, these are largely inconsistent with the extant literature and therefore further work is needed. However, the current study highlights the importance for cognitive control studies to contextualize their results in the specifics of the task used. Given that different behavioral tasks elicit cognitive control through similar but separate neural mechanisms, the behavioral task utilized when investigating the relationship between self-report, behavioral, and physiological measures should be heavily scrutinized.

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