# ASSOCIATIONS BETWEEN RETROSPECTIVE ODD, CONCURRENT ADHD, EXECUTIVE FUNCTION, AND FRONTAL EEG ACTIVATION IN COLLEGE STUDENTS

A thesis presented to the faculty of the Graduate School of Western Carolina University in partial fulfillment of the requirements of the degree of Master of Arts in Clinical Psychology.

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TABLE OF CONTENTS

LIST OF TABLES

# LIST OF ABBREVIATIONS

Attention-Deficit/Hyperactivity Disorder (ADHD)

Attention Network Test (ANT)

Adult ADHD Self-Report Scale (ASRS)

Behavior Rating Inventory of Executive Function for Adults (BRIEF-A)

Behavioral Regulation Index (BRI)

Bipolar Disorder (BD)

Conduct Disorder (CD)

Disruptive Behavior Disorder (DBD)

Dorsolateral Prefrontal Cortex (dlPFC)

Electroencephalogram (EEG)

Executive Function (EF)

Global Executive Composite (GEC)

Go/No Go Task (GNG)

Metacognition Index (MCI)

Oppositional Defiant Disorder (ODD)

Oppositional Defiant Behavior Inventory (ODBI)

# ABSTRACT

ASSOCIATIONS BETWEEN RETROSPECTIVE ODD, CONCURRENT ADHD, EXECUTIVE FUNCTION, AND FRONTAL EEG ACTIVATION IN COLLEGE STUDENTS

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Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most prominent disorders with five percent of children and two and a half percent of adults diagnosed. Posner's attentional theory consists of three attentional networks: orienting to sensory stimuli, activating ideas from memory, and maintaining the alert state. Executive function (EF) has been heavily researched for its association with ADHD, specifically with inattention deficits using the attentional networks mentioned above. Inattention has been found to be closely related with struggles of academic achievement indicating the importance for intervention at an early age. The three domains of EF: response inhibition, working memory, and cognitive flexibility have been researched using a hot and cool model. Cool executive functioning includes attention control, inhibition, and working memory associated with lateral prefrontal cortex (PFC) areas. Hot executive functioning includes emotional, motivational, and reward/punishment associated with the medial PFC areas. ADHD is also highly comorbid with oppositional defiant disorder (ODD) diagnosed in approximately 50% of children with ADHD. Comorbid ODD has been found to correlate with increased deficits for ADHD indicating more severe symptomology. Research has found individuals diagnosed with ADHD with or without comorbid ODD perform more poorly on cool tasks indicating ADHD is associated with cool EF. Researchers have also found ODD with or without comorbid ADHD is associated with hot EF. The electroencephalogram (EEG) is an objective measure of electrical

activity in the brain using electrodes placed on the scalp. EEG spectral power has been found to be the best predictor for distinguishing ADHD, although different frequency bands have been associated with ADHD when comparing children and adults. The alpha band (8-12Hz) was used in this study, as it has been shown to have reduced power in the lower alpha band and elevated power in the upper band for adults. The current study aimed to determine the predictive power of EF and change in EEG power for concurrent ADHD and retrospective ODD symptomology in college students, as well as group differences in change in power across an ADHD+ODD, ADHD alone, and control group. Analyses determined positive correlations between the three self-reports for ADHD and ODD symptomology as well as EF abilities. Regression analyses were also significant, which indicated ADHD symptomology was predicted by EF ability and change scores of EEG mean power in F3 and F4 electrodes for the alpha band. When comparing group differences for change in EEG, I found the three groups to have no significant difference in change in EEG power. These results illustrate the utility and predictive power EEG has when distinguishing ADHD symptomology. EEG could be used as an objective diagnostic tool to give clinicians more insight to be able to make an informed decision for possible diagnoses.

# INTRODUCTION

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most prominent disorders diagnosed in children and adults. According to the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; DSM-5; American Psychiatric Association [APA], 2013), five percent of children and two and a half percent of adults are diagnosed with ADHD. ADHD symptoms can show a pattern of two different subtypes: inattention and/or hyperactivity-impulsivity. Common difficulties for the inattention subtype include sustaining attention, organizing and following through with tasks, and not listening when spoken directly to. Some common difficulties for the hyperactivity-impulsivity subtype include inhibiting actions like fidgeting and outbursts, talking excessively, and interrupting or intruding on others (APA, 2013). Salvi et al. (2019) conducted a study to determine the prevalence of ADHD subtypes in adults. They found 18% of their sample classified as the inattentive subtype, 8% as the hyperactivity-impulsivity subtype, and 70% as the combined subtype. These findings illustrate when differentiating between the two subtypes, more individuals experience deficits related to attention than impulsivity (Salvi et al., 2019; Wilens et al., 2010).

Posner (1994) defined attention as an individual identifying one clear and vivid object or train of thought out of several simultaneous thoughts. Posner's theory of attentional networks included orienting to sensory stimuli, activating ideas from memory, and maintaining the alert state. Berger and Posner (2000) considered Posner's attentional theory related to ADHD and concluded that ADHD is associated with deficits in frontal structures in the brain. These deficits were consistent with two of the three attentional networks: executive function/effortful control and vigilance and alerting regulation. Lundervold et al. (2011) assessed the three attentional networks in ADHD and found adults with ADHD were generally less accurate, having a

significantly higher number of omission errors than controls during the attention network test (ANT). The ANT is a common flanker task where stimuli are shown with distractors around them, specifically five arrows that are in an array pointing left or right, and the participant indicates which way the center arrow is pointing as fast as they can (Fan et at., 2002). The ADHD group also had higher variability in scores and lower vigilance, meaning individuals with ADHD were not able to sustain their attention and awareness on the task. Participants were also slower and more distracted when presented with conflicting stimuli during the ANT (Lundervold et al., 2011). Individuals with ADHD have delayed responses, increased reaction time variability, and reduced inhibition during a Go/No Go task consistent with difficulties discussed above (Grane et al., 2014).

ADHD is highly comorbid with oppositional defiant disorder (ODD), which is diagnosed in approximately 50% of children with ADHD (APA, 2013). ODD consists of symptoms including an irritable or angry mood, vindictiveness, arguing or refusing to comply with an authoritative figure, or deliberately annoying others. ODD is often diagnosed in preschool years or early adolescence at an average prevalence rate of three percent (APA, 2013) and approximately 40% of boys diagnosed with ODD went on to receive a diagnosis of conduct disorder (CD; Rowe et al., 2002). CD includes the pattern of vindictiveness and problems with authority found in ODD but also includes aggression, destruction of property, and theft. When controlling for ADHD symptoms, increased ODD severity was found to correlate with more social impairment, difficulties in romantic relationships, antagonistic online behavior, conflict with authority figures, and thoughts about dropping out of college (Johnson et al., 2018). Comorbidity of ODD with ADHD is associated with higher scores of inattention, hyperactivity,

and impulsivity when compared with individuals diagnosed with only ADHD (Tahillioglu et al., 2021).

**Executive Function**

Executive function (EF) has long been a construct associated with ADHD. Executive function can be defined as an individual's ability to self-regulate or control cognitive processes in day-to-day routines (Miyake et al., 2000). Impairments of executive function are specific to attention symptoms of ADHD and not hyperactivity (Willcutt et al., 2005), with previous research that suggests the ADHD inattention subtype to be more closely related with struggles of academic achievement (Massetti et al., 2007). According to a review by Salehinejad et al. (2021), there is a general agreement among the literature for the three domains of executive function: response inhibition, working memory, and cognitive flexibility (Miyake et al., 2000).

When looking at specific deficits within these three domains, ADHD is found to be most associated with deficits in inhibition, attention, set-shifting, verbal learning, and verbal memory when compared with other comorbid disorders and healthy controls (Bayraktar et al., 2019). The Behavior Rating Inventory of Executive Function (BRIEF) is a rating scale used to assess executive function abilities comprised of nine clinical scales: inhibit, shift, emotional control, self-monitor, initiate, working memory, plan/organize, task monitor, and organization of materials, as well as two broad indices: the behavioral regulation index (BRI) and the metacognition index (MCI), and finally an overall composite score called the global executive composite (GEC; Roth et al., 2005). Mahone et al. (2002) found when comparing measures of executive function, specifically the BRIEF-Parent Form and performance-based measures such as the Go/No Go task, were found to be correlated very weakly in children aged six to sixteen.

The BRIEF was strongly associated with ADHD symptomology, specifically the working memory and inhibit scales of the BRIEF were useful in differentiating subtypes of ADHD (Mahone et al., 2002). When looking at longitudinal deficits of executive function in ADHD, Behnoosh et al. (2021) found that deficits of planning time, set-shifting, response inhibition, impulsivity, and visuolingual processing continue to persist into adult ADHD while sustained attention seems to increase as individuals get older.

The two domains of ADHD, inattention and hyperactivity, are researched in much of the literature using different theoretical models, such as the hot and cool model of executive functioning (Zelazo & Carlson, 2012). Cool executive functioning includes attention control, inhibition, error detection, and working memory that are found to be associated with more lateral prefrontal cortex areas (Salehinejad et al., 2021). Hot executive functioning is more emotional, motivational, reward/punishment based on social stimuli and found to be associated with more medial and orbital prefrontal cortex areas (Salehinejad et al., 2021). Yang et al. (2011) found children with ADHD perform significantly worse on measures of response inhibition, working memory, and delay aversion. According to these findings, ADHD is associated with both cool and hot domains of executive functioning.

**ADHD in College Students**

Massetti et al. (2007) conducted a longitudinal study to determine academic deficits in children with ADHD. They found children with the inattentive subtype of ADHD to have lower reading, spelling, and mathematic scores when compared to other ADHD subtypes, and controls. Scholtens et al. (2013) also found participants with ADHD at a young age were affected negatively in academic achievement concurrently and longitudinally. These studies illustrate the

importance and need for early interventions for children with ADHD, especially children with attention problems, to combat these obstacles and increase academic achievement as a child. Individuals entering college at the undergraduate level with ADHD have also been found to have poor academic achievement making early intervention and diagnosis an important topic for research (Dou et al., 2022). Dou and colleagues investigated the effect academic enablers such as study skills, engagement, and motivation had on academic achievement. They found these academic enablers to predict greater academic achievement among university students. This would suggest diagnosing ADHD at an early age could result in students practicing these academic enablers before entering college and increasing academic achievement (Dou et al., 2022).

When looking at executive functioning with ADHD and comorbid ODD, Antonini et al. (2015) found that when compared with controls, those with ADHD regardless of ODD performed more poorly on cool tasks of executive function. However, performance on the hot executive function tasks did not differ significantly between all groups within the study. Therefore, these findings show individuals with symptoms of ADHD, not symptoms of ODD, are associated with cool executive function performance. However, the associations between ADHD and ODD with performance measures remains unclear. Hummer et al. (2011) conducted a study looking at executive function in groups of adolescents with an average age of 13, ranging from 10 to 17 years old, with disruptive behavior disorders (DBD), which includes ODD, and ADHD. They found participants with DBD, and comorbid ADHD performed significantly worse on neurocognitive measures and questionnaires when compared to the DBD alone and control groups. These findings suggest individuals with comorbid DBD and ADHD have increased deficits for executive functioning than individuals with ADHD alone. Hobson et al. (2011) also

investigated whether ODD/CD is related to executive functioning independently of ADHD. They found those with ODD/CD with or without comorbid ADHD to be significantly impaired in cool executive functioning measures. Researchers also found ODD/CD to be associated with hot executive function measures while ADHD symptoms were not (Hobson et al., 2011).

**Electroencephalogram and ADHD**

EEG is a measure of electrical activity in the brain that reflects groups of active neurons from the cortex; these changes in brain electrical signals are measured by placing electrodes on top of the scalp and analyzing dominant frequency bands. Various studies have investigated the power of frequency bands in those with ADHD, ODD, and comorbidly diagnosed participants. EEG spectral power is calculated by the density of frequency between a group of electrodes on the EEG cap. These frequency bands include delta (1-3Hz), theta (4-7Hz), alpha (8-12Hz), beta (13-30Hz), and gamma (30-100Hz). Eyes-open spectral power has been found to be the best predictor for distinguishing ADHD from controls, specifically showing an increase in central-delta and left-parietal-delta, central-alpha-low and parietal-alpha-low, and right-beta-low power (Kiiski et al., 2019). These results indicate the utility resting state EEG spectral power has as a biomarker for individuals with ADHD.

Markovska-Simoska & Pop-Jordanova (2017) conducted a longitudinal study where they found children with ADHD showed greater relative power in delta and theta bands than when they became adults. After becoming adults, the same participants with ADHD showed more relative power in alpha and beta bands. These findings illustrate the progression of EEG frequency bands for individuals with ADHD as they get older. Another study looked at whether children outgrew their ADHD diagnoses as adults and showed that children with ADHD have

increased absolute and relative theta, reduced relative alpha, and an increased theta/beta ratio. Once these children reached adulthood, the children who did not grow out of their ADHD were found to have greater relative beta, reduced frontal relative theta, and increased frontal absolute and relative beta (Clarke et al., 2010). In the current study, I focus on the alpha band (8-12 Hz) as adults with ADHD have been found to show significant increases in the absolute power density in the alpha frequency band (Koehler et al., 2009). According to Debnath et al. (2021), individuals with ADHD showed reduced power and connectivity in the lower alpha band when compared to controls and that EEG power in the lower alpha band were negatively associated with ADHD severity (Debnath et al., 2021).

Few studies have investigated the comparison between baseline and task spectral power, especially in the alpha band. Bell (2002) conducted a study comparing baseline EEG spectral power to task spectral power using a spatial working memory task with infants. This study found a significant difference between baseline spectral power and task spectral power. Specifically, the spectral power for task performance was significantly higher than baseline performance. Rommel et al. (2016) also conducted a study comparing EEG spectral power during a cognitive task with spectral power during baseline in the theta band for women with ADHD and bipolar disorder (BD). They found increased spectral power for the baseline task when comparing the ADHD and BD groups to the controls. They also found the control group showed an increase for task-related power compared to resting state in the theta band (Rommel et al., 2016). These findings indicate a significant increase of brain activity in task-related spectral power compared to resting-state or baseline spectral power, which may indicate an increase in cognitive load during cognitive tasks. I am not aware of any studies that have investigated associations between change scores of baseline and task spectral power. Therefore, this study investigated the utility

and association change scores between task and baseline spectral power might have with ADHD and ODD symptomology, which are calculated by subtracting task EEG spectral power from baseline EEG spectral power.

Various researchers have investigated whether different areas of the brain are responsible for ADHD and comorbid ODD. Rubia et al. (2008) conducted a study on inhibition in boys with CD or ADHD using fMRI and found activation in the left dorsolateral prefrontal cortex (dlPFC) for boys with ADHD during successful inhibition when compared to CD, which is also associated with the cool executive functioning domain (Salehinejad et al., 2021). When participants failed to inhibit responses, they found under activation in the posterior cingulate gyrus. The researchers concluded the prefrontal region is significantly reduced in activation for individuals with ADHD and reduced in posterior temporal-parietal regions for CD when failing to inhibit responses during the Stop Task, an inhibitory control task. Clarke et al. (2002) found ADHD groups to have less relative alpha power, more relative delta power in posterior regions, and less relative beta power in frontal regions when compared with controls. These findings support the conclusion that ADHD symptomology alone may be related to differences found in EEG power with or without comorbid ODD in children, which brings us to my current study.

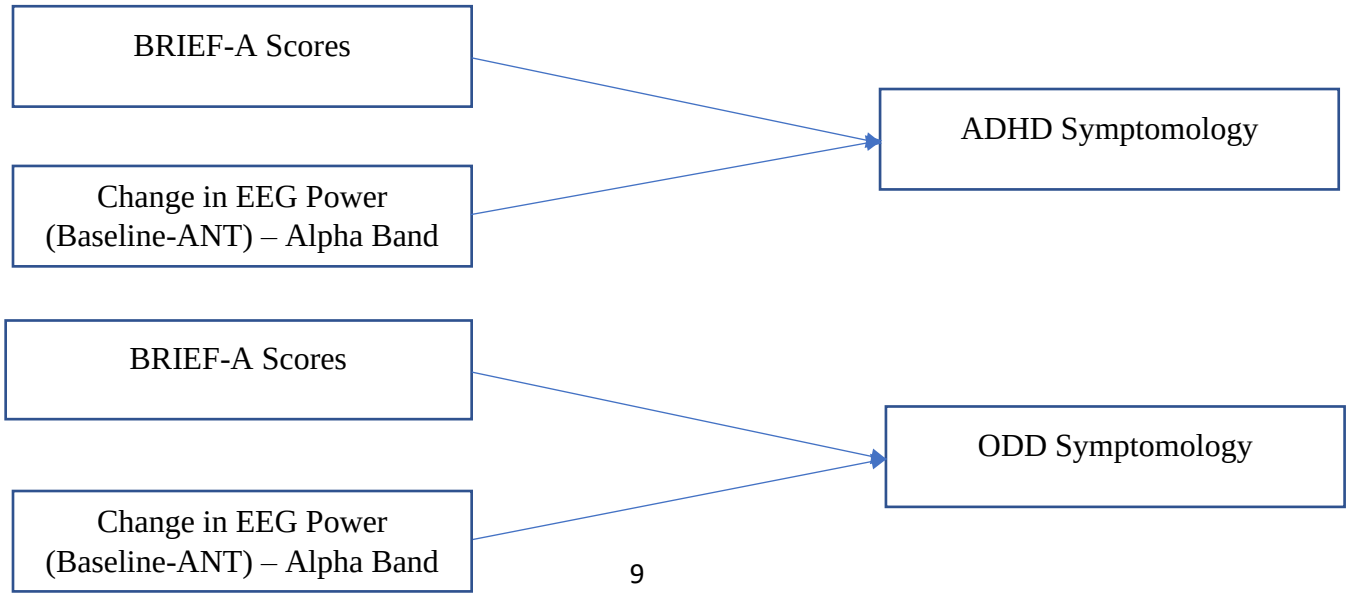
**The Current Study**

The current study focuses on determining the predictive ability of executive function and change in EEG power for concurrent ADHD and retrospective ODD symptomology in college students. Past research has investigated the relationship between EEG activation and groups of ADHD and comorbid ODD thoroughly for children but not in a college population. No research has yet investigated the relationship with executive functioning and EEG power as possible

predictors of concurrent ADHD and ODD symptomology. This study aimed to determine whether BRIEF-A composite scores and change in EEG power at the alpha band, as past literature has shown evidence for the alpha band to be highly correlated with ADHD symptomology, can predict concurrent ADHD and retrospective ODD symptomology.

Three different groups were determined based on scores from the ADHD and ODD self-reports: concurrent ADHD symptomology with retrospective ODD symptomology (ADHD + ODD), concurrent ADHD (ADHD) symptomology alone, and a control group (HC). These three groups compared change in EEG spectral power for the alpha band during an attention task (subtracting ANT EEG power from baseline) to determine whether individuals in the ADHD + ODD group have larger change in power compared to individuals in the ADHD and control groups. Finally, to assess neural patterns of the hot and cool domains of executive function, the three groups' change in EEG power of the alpha band was compared during the Go/No Go task (subtracting Go/No Go EEG power from baseline) and the delay discounting task (subtracting delay discounting EEG power from baseline).

Model:



Hypotheses:

1. Executive function abilities would be negatively correlated with ADHD symptomology and change in EEG spectral power of the alpha band during the attention task would be positively correlated with ADHD symptomology.
    - I used a linear regression to determine if higher BRIEF-A scores and increased change in EEG power of the alpha band predicted an increase in self-reported ADHD symptoms.
2. Executive function abilities would be positively correlated with ODD symptoms while change in EEG power of the alpha band during the attention task would not differ for the amount of ODD symptoms.
    - I used a linear regression to determine whether higher BRIEF-A and change in EEG power of the alpha band were associated with higher self-reported retrospective ODD symptoms.
3. Frontal EEG power change (F3 & F4) in the alpha band (8-12Hz) would be significantly increased in the ADHD+ODD and ADHD groups compared to the HC during the ANT, but ADHD+ODD and ADHD groups were hypothesized to not be significantly different.
    - I used a MANOVA to compare groups mean scores on change in EEG power during the ANT.

3a. Frontal EEG power change (F7 & F8) in the alpha band for the delay discounting task would be significantly increased in the ADHD+ODD and ADHD only group when comparing the control group. I also hypothesized that the increase in power change would be significantly increased when comparing the ADHD+ODD group to the ADHD only group.

- I used a MANOVA to compare group mean scores on change in EEG power during the delay discounting task.

3b. Frontal EEG power change (F3 & F4) in the alpha band for the Go/No Go task would not be significantly different in any of the three groups.

- I used a MANOVA to compare group mean scores on change in EEG power during the Go/No Go Task.

## METHODS

### Participants

Individuals were recruited from a rural, mid-sized university in the southeastern United States through SONA systems, specifically individuals taking general psychology classes. The completed number of subjects was 55, although one participant was unable to complete EEG data due to the cap not fitting properly. The majority of participants identified as female and white with a mean age of 18.5 ranging from 17 to 27-years-old (Table 1.) Individuals received 2 research credits as compensation through SONA systems for course credit.

**Table 1.**

*Demographics of Participants*

| Gender | Frequency | Percentage |
|---|---|---|
| Male | 13 | 24.1 |
| Female | 37 | 68.5 |
| Non-binary | 4 | 7.4 |
| Race | | |
| Asian | 2 | 3.7 |
| Black/African American | 5 | 9.3 |
| White | 42 | 77.8 |
| American Indian/Native American or Alaska Native | 1 | 1.9 |
| Multi-racial | 4 | 7.4 |
| Ethnicity | | |
| Hispanic | 5 | 9.1 |
| Non-Hispanic | 49 | 89.1 |
| Handedness | | |
| Right-handed | 43 | 78.2 |
| Left-handed | 8 | 14.5 |
| Ambidextrous | 3 | 5.5 |

**Note.** N = 54. Average age is 18.5 with a range from 17-27. The multi-racial group includes participants who chose two or more of the racial identities above.

## Measures

### *Adult ADHD Self-Report Scale (ASRS; Kessler et al., 2005)*

The ASRS is an 18-item checklist consisting of a six-item screener to determine individuals at risk for ADHD and with 12 more items evaluating the severity of inattention, impulsive, and hyperactive symptoms. These items are answered using a five-point Likert scale from 0 (*never*) to 4 (*very often*). All 18-items were used as a total score when looking at predictive abilities of EEG and ADHD symptomology. For the first three items of the screener (items 1-3), participants who identified with a two or higher on the Likert scale scored one point for each item. For the last three items of the screener (items 4-6), participants who identified with a three or higher on the Likert scale were scored as a 1. Individuals who scored a four or higher

on the first six questions were classified as “at-risk” for ADHD. The scores of the first six items were used to complete the groups for hypothesis 3, 3a, and 3b as well as analyses comparing the three groups. Adler et al. (2006) found internal consistency for this measure to be high (α = .84), as well as high concurrent validity (α = .83). These correlations show the ASRS to have good reliability and validity. The ASRS was also found to have high negative predictive power of ADHD symptoms (NPP = .97) showing a reduced number of false negatives for individuals at-risk for ADHD (Glind et al., 2013). Cronbach’s alpha was completed and found to be satisfactory when compared to past literature (α = .939)

***Oppositional Defiant Behavior Inventory (ODBI; Harada et al., 2004)***

The ODBI is an 18-item inventory using a four-point Likert scale, 0 (*once a month or less*) to 3 (*4 times a week or more*) to evaluate for a possible diagnosis of ODD. The original ODBI is an informant report but was adapted to a self-report asking participants about retrospective ODD (Appendix B). For example, the original ODBI asks “How often have you observed the following behavior?” from 0 (*once a month or less*) to 3 (*4 times a week or more*), with one item being “has temper tantrums when things do not go as he/she wishes.” The adapted retrospective scale asked, “How often do you remember doing the following behaviors during your childhood (Age 8-10; Grade 3-5)?”, with the item changed to “had temper tantrums when things did not go as you wished”.

Harada et al. (2004) found the ODBI to have high internal consistency (α = .925) and test-retest reliability (α = .820). Concurrent validity was also tested by correlating the ODBI with the DSM-IV ODD criteria (*r* = .660, .659) and with the Disruptive Behavior Disorders Rating Scale (DBDRS)-ODD (*r* = .725, .654). Concurrent validity was found to be satisfactory. Cronbach’s alpha was completed for the current study to determine reliability for the modified

ODBI (α = .937) which was consistent with past literature of the original measure. Divergent validity was also satisfactory showing between the three groups of ADHD, ADHD+ODD, and a control group scores for the ADHD+ODD group had significantly higher scores on the ODBI than the other two groups (Harada et al., 2004). The ODBI was chosen due to its divergent validity between ADHD and ADHD+ODD and its precision and specificity within each item.

***Behavior Rating Inventory of Executive Function for Adults (BRIEF-A; Roth et al., 2005)***

BRIEF-A is a 75-item self-report measure that determines an individual's executive function abilities. The BRIEF-A is made up of nine clinical scales: inhibit, shift, emotional control, self-monitor, initiate, working memory, plan/organize, task monitor, and organization of materials. These scales make up two broad indices: the behavioral regulation index and the metacognition index. There is an overall summary of composite scores called the global executive composite (GEC). Participants responses were scored as a raw score and then converted into the GEC T-scores, which were used in the analyses. There are also three validity scales measuring inconsistency, infrequency, and unusually negative response patterns. Validity scales were also calculated to determine any participants that might have invalidated the protocol. Only one participant was reviewed with caution due to an elevation for negative response patterns one point above the elevation cutoff. No participants were excluded based on validity scale scores. The BRIEF-A has been found to have high correlations in test-retest scores ($r$ = .82-.94) showing high reliability. Interrater correlations ranged from .44 to .68 for clinical scales and .61-.63 across the indices (Roth et al., 2005). Cronbach's alpha was completed to determine the reliability of the BRIEF-A in the current study. Analyses indicated satisfactory reliability scores as compared to past literature (α = .979).

### *Attention Network Test (ANT; Fan et al., 2002; Posner, 1994)*

ANT measures an individual's ability to concentrate and focus their attention during a task. Three specific components of attention were assessed during the ANT: executive control, alerting, and orienting. The ANT is a common flanker task where stimuli are shown with distractors around them, specifically five arrows will be in an array pointing left or right and the participant has to indicate which way the center arrow is pointing as fast as they can. Participants completed 288 trials. Fan et al. (2002) found test-retest reliability to be the most reliable for the executive control component ($r$ = .77), intermediate reliability for the orienting component ($r$ = .61), and finally the lowest reliability for the alerting component ($r$ = .52). Reaction times across two sessions were found to be highly correlated with one another ($r$ = .87; Fan et al., 2002). Participants completed the ANT task developed by Wang et al. (2015) using the Inquisit 6.5 software browser developed by Millisecond.

### *Go/No Go Task (GNG; Fillmore et al., 2006)*

GNG measures individual's levels of impulsivity. For this specific task, participants were shown a white rectangle. If the white rectangle turned green, the participant pressed the space bar (go condition). If the white rectangle turned blue, the participant was instructed to inhibit any response and not press the space bar (no-go condition). Participants completed 250 trials altogether with 125 trials for each the go- and no-go conditions. The GNG was used to investigate the hyperactivity and inhibition component of ADHD (Grane et al., 2014) and the cool domain of executive functioning (Salehinejad et al., 2021). Langenecker et al. (2007) found the GNG task to show increased difficulty in the attention control, set-shifting accuracy, and inhibitory control. They also found evidence for moderate convergent validity ($r$ = .28-.51), specifically the GNG was significantly correlated with both simple and complex executive

function tasks. Test-retest reliability was also assessed; strong reliability was found ranging from $r$ = .57-.83 (Langenecker et al., 2007). Participants completed this task using the Inquisit 6.5 software browser.

### *5-trial Delay Discounting Task (Koffarnus et al., 2014)*

The 5-trial delay discounting task is a 5-item task with forced-choice response where participants chose between immediate and delayed options of money. Participants were given a choice every time of five dollars now or ten dollars in a certain delayed time. An immediate and delayed response was presented and depending on the participant's response the next presented forced choice amount would be adjusted based on a computer algorithm. For example, the choices could be "$5 now" or "$10 in three weeks." If they chose the five dollars now, the delay of three weeks would be adjusted by the algorithm for your next choice to be "$5 now" or "$10 in one day." These five trials would continue to adjust to find the indifference point or subjective value participants placed on rewards to determine how long participants were willing to wait for a larger reward before the immediate smaller reward became more valuable. In this study, a delay-discounting task was included because these tasks have shown strong reliability and moderate discriminant ability for detecting self-reported ADHD (Hurst et al., 2011) as well as assessing components of hot executive functioning (Salehinejad et al., 2021).

### *Electroencephalogram (EEG)*

EEG was used to measure brain waves, specifically cortical activity, during a task and resting state. In this study, frontal medial electrodes (F3 and F4) during the ANT and GNG and frontal lateral electrodes (F7 and F8) during the delay discounting task were used to calculate EEG frontal power in the alpha frequency band (8-12 hz). Participants' EEG resting-state or

eyes-open baseline was measured by having the participants stare at an “x” on a white wall for one minute. To measure EEG, the BrainVision ActiCHAMP system was used with 32 electrode caps (BrainVision Analyzer, 2019). BrainVision Recorder was used to record electrical signals at the level of the scalp. These recordings were then filtered through MATLAB before computing change scores at F3, F4, F7, and F8 electrodes. EEG data was cleaned using a multiple step protocol. The data was first cleaned by rejecting noisy data or interpolating specific electrodes if needed. Data was then run through ”cleanline” pipeline to remove any artifacts and noise in the data. Independent component analyses (ICAs) were then run, and specific components were rejected using EEGLAB. A final rejection of the data was completed manually in EEGLAB for any other outlying data or artifacts. Tasks were then separated by rejecting all other data outside the tasks using EEGLAB. The average number of seconds rejected from the data was 199 seconds with an average length of files being 2045 seconds after being cleaned. Each baseline and task dataset was then run through the mean power spectral script (Appendix C) to calculate spectral power for the alpha band (8-12 Hz) at F3, F4, F7, and F8. Change scores were then computed by subtracting task spectral power from baseline spectral power at each electrode. Change in EEG power represents neural activation during a cognitive task and was the measure of interest.

**Procedure**

Participants were recruited using SONA systems from introductory psychology classes to come into the Cognitive Neuroscience Laboratory at Western Carolina University. The researcher first introduced the informed consent where participants then were asked to sign to participate in the study. Participants were then taken into the lab area where they filled out questionnaires including demographics, concurrent ADHD symptomology using the ASRS,

retrospective ODD symptomology from when the participant was 8-10 years old using the ODBI, and executive functioning using the BRIEF-A. After filling out questionnaires, participants were fitted for an EEG cap and then completed a resting state EEG including eyes open condition where they stared at a fixation cross on the wall, an eyes closed condition, and finally watched nature video. Participants then completed the Attention Network Test, the Go/No Go task, and the Delay Discounting Task using Inquisit Browser. These three tasks were administered using a Latin Square design to alleviate order effects.

**Analyses**

Cronbach's alpha was calculated to determine reliability for the ADHD and ODD self-reports that were adapted to ask about retrospective and concurrent symptomology. To address hypothesis 1, correlations and a linear regression were run to determine if higher scores on the BRIEF-A and increased task-related change in EEG mean power were associated with higher self-reported ADHD symptomology. To address hypothesis 2, I also ran a linear regression to determine if higher scores on the BRIEF-A were associated with higher self-reported ODD symptomology, and if change in EEG power during the ANT would not show any association with ODD symptomology. Then to address hypothesis three, I ran a multivariate analysis of variance (MANOVA) to determine if there were any group differences within the three groups of ADHD and ODD symptomology, ADHD symptomology alone, and a control group with frontal EEG power change (F3 & F4) in the alpha band during the attention network test. To address hypothesis 3a, I also used a MANOVA to determine if the three groups were different in frontal EEG power change (F7 & F8) during the delay discounting task. Finally, I ran another MANOVA to determine if there were any group differences in average frontal EEG power change (F3 & F4) during the Go/No Go task to address hypothesis 3b.

***Group assignment***

Groups were determined through responses on both the ASRS and ODBI. First, scores were calculated for the ASRS using the first six items. Kessler et al.'s (2005) scoring procedure of the ASRS included the first six items were used as a screening instrument being most predictive of ADHD with a score of 4 or more indicating a high consistency for ADHD, although further investigation is still warranted. Individuals who met the 4 or more cutoff but did not meet the ODBI cutoff were included in the concurrent ADHD alone group. ODBI scores were coded by summing all 18 retrospective item responses to calculate a total score. Harada et al. (2008) conducted a study to establish cut-off points for scoring the ODBI. They established a cut-off of 20 points indicated 88.2% sensitivity, 90% specificity, 75% positive predictive value, and 95.7% predictive value for distinguishing children eligible for an oppositional defiant disorder diagnosis from those who are not. This cutoff was used to create an ODD only group which then was used to create the concurrent ADHD and retrospective ODD group by including participants who met the cutoff for the ASRS and the ODBI. Finally, individuals who did not meet the cutoff for either the ASRS or ODBI were classified as the control group. Final groups were determined including 19 participants for the ADHD and ODD group, 9 in the ADHD only group, and 25 in the healthy control group.

## RESULTS

Mean and standard deviation for the overall sample as well as between each group were reported below (Table 2.) These scores are similar when compared to past literature for both the ASRS total scores and BRIEF-A T-scores (Gray et al., 2014; Grieve et al., 2014). The ODBI is more specific for children not college students so comparisons in scores were not made. A multivariate *post hoc* analysis determined if there were any differences across gender for all three

self-report measures: ASRS and ODBI raw scores as well as BRIEF-A GEC t scores. No significant differences were found across gender groups for any of the self-report measures. Bivariate correlations were conducted to determine the relationship between ASRS scores, ODBI scores, BRIEF-A scores, and change scores for EEG mean power for the ANT and baseline measures. No significant correlations were found between the questionnaires and change in EEG mean power between the ANT and baseline, which did not support our first hypothesis (Table 3.) Although, the ASRS, ODBI, and BRIEF-A were all highly correlated with the ASRS and BRIEF-A showing the highest correlation ($r$ = .822, $p$ <.001).

**Table 2.**

*Mean and Standard Deviations across Self-Report Measures in the Overall Sample and Between Groups*

| | | | Groups | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | ADHD+ODD | | ADHD Only | | Healthy Controls | |
| | Overall Sample | | | | | | | |
| Questionnaires | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| ASRS | 56.13 | 14.29 | 69 | 7.75 | 64.89 | 7.08 | 43.69 | 7.70 |
| ODBI | 36.80 | 11.57 | 47.42 | 7.99 | 31.67 | 4.72 | 30.81 | 9.92 |
| BRIEF-A | 68.06 | 15.48 | 80.68 | 11.66 | 75 | 8.90 | 56.42 | 10.27 |

**Note.** BRIEF-A means and standard deviations were reported based off of T-scores. The overall sample includes all 54 participants.

**Table 3.**

*Associations of Change in EEG Mean Power, Executive Function, and ADHD and ODD Symptomology*

| | Questionnaires | | |
|---|---|---|---|
| | Concurrent ASRS | BRIEF-A | Retrospective ODBI |
| Concurrent ASRS | 1 | .82** | .58** |
| Retrospective ODBI | .58** | .59** | 1 |
| Delta_bso_ANT_F3 | .18 | .04 | .13 |
| Delta_bso_ANT_F4 | .15 | .10 | .09 |
| Delta_bso_ANT_F7 | .14 | .02 | .06 |
| Delta_bso_ANT_F8 | .16 | .08 | .03 |
| Delta_bsc_ANT_F3 | .04 | -.02 | -.08 |
| Delta_bsc_ANT_F4 | -.04 | -.08 | -.13 |
| Delta_bsc_ANT_F7 | -.01 | -.06 | -.14 |
| Delta_bsc_ANT_F8 | -.04 | -.08 | -.14 |
| Delta_bsv_ANT_F3 | .22 | .11 | .14 |
| Delta_bsv_ANT_F4 | .19 | .12 | .03 |
| Delta_bsv_ANT_F7 | .11 | .02 | .02 |
| Delta_bsv_ANT_F8 | .11 | .05 | -.02 |

**Note.** *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the .01 level (2-tailed). $N = 53$.

A linear regression was calculated to determine whether EEG mean power change scores of the ANT and baseline in the F3 and F4 electrodes as well as BRIEF-A scores would be able to predict ASRS scores. Significant results were found ($F(3, 49) = 40.77$, $p < .001$) with an $R^2$ of .714 (Table 4.) These results support our hypothesis that EEG change in power of the alpha band and BRIEF-A scores are predictive factors for ASRS scores, which measure at-risk populations for ADHD.

**Table 4.**

*Results of Regression Analyses of Frontal Activation Correlating with ADHD Symptoms and Executive Functioning*

| | Adult ADHD Self-Report Scale (ASRS) | | | |
|---|---|---|---|---|
| | *B* | *SE* | β | *p* |
| BRIEF-A | 0.76 | 0.07 | 0.84 | < .001 |
| Δ F3 | 4.34 | 1.64 | 0.52* | .011* |
| Δ F4 | -3.37 | 1.62 | -0.41* | .043* |
| | | | $R^2$ = .71* | |

**Note.** *$p$ < .05. N = 53. Positive beta values are associated with higher ASRS scores and more change in activation during the ANT. Change scores are calculated from subtracting baseline eyes open mean power from mean power during the ANT.

A linear regression was also calculated to determine whether EEG mean power change scores of the ANT and baseline in the F3 and F4 electrodes as well as BRIEF-A scores would be able to predict ODBI scores. The regression was also significant ($F(3, 49) = 9.43$, $p < .001$) with an $R^2$ of .36 (Table 5.) These results were only significant for the BRIEF-A in being able to predict ODBI scores not EEG mean power, which is consistent with our hypothesis that change in EEG power would not be significantly associated with ODBI scores.

**Table 5.**

*Results of Regression Analyses of Frontal Activation Correlating with ODD Symptoms and Executive Functioning*

| | Oppositional Defiant Behavior Inventory (ODBI) | | | |
|---|---|---|---|---|
| | *B* | *SE* | β | *p* |
| BRIEF-A | 0.45 | 0.09 | 0.60 | < .001 |
| Δ F3 | 3.05 | 2.02 | 0.44 | .138 |
| Δ F4 | -2.51 | 1.99 | 0.04 | .213 |
| | | | $R^2 = 0.37$ | |

**Note.** *$p < .05$. $N = 53$. Positive beta values are associated with higher ODBI scores and more change in activation during the ANT. Change scores are calculated from subtracting baseline eyes open mean power from mean power during the ANT.

Finally, three different multivariate general linear models (MANOVAs) were conducted to determine differences between three groups: concurrent ADHD and retrospective ODD (ADHD+ODD), concurrent ADHD alone (ADHD), and a control group (HC). The first MANOVA conducted investigated whether EEG power change scores during the ANT and baseline of F3 and F4 electrodes of the alpha band were significantly increased in the ADHD+ODD and ADHD groups compared to the HC and whether the ADHD+ODD and ADHD groups were significantly different. Analyses indicated no significant differences for change in EEG power between any of the three groups, which did not support hypothesis 3 (Table 6.)

**Table 6.**

*Results of MANOVA for Comparing Frontal Power change of the alpha band during the Attention Network Test between ADHD and ODD symptomology, ADHD alone, and control groups*

| Source | Dependent Variable | Sum of Squares | *df* | Mean Square | F | *p* | Partial $\eta^2$ |
|---|---|---|---|---|---|---|---|
| Intercept | Δ F3 | .20 | 1 | .20 | .07 | .793 | .00 |
| | Δ F4 | .01 | 1 | .01 | .00 | .954 | .00 |
| Groups | Δ F3 | 3.29 | 2 | 1.65 | .57 | .567 | .02 |
| | Δ F4 | 8.40 | 2 | 4.20 | 1.46 | .242 | .06 |

**Note.** *$p < .05$. $N = 53$.

The second MANOVA conducted investigated whether EEG power change scores during the delay discounting task and baseline in F7 and F8 electrodes of the alpha band were significantly different when comparing the three groups. Analyses also indicated no significant differences between change in EEG power for any of the three groups again not supporting hypothesis 3a (Table 7.)

**Table 7.**

*Results of MANOVA for Comparing Frontal Power change of the alpha band during a Delay Discounting Task between ADHD and ODD symptomology, ADHD alone, and control groups*

| Source | Dependent Variable | Sum of Squares | *df* | Mean Square | F | *p* | Partial $\eta^2$ |
|---|---|---|---|---|---|---|---|
| Intercept | Δ F7 | 202.48 | 1 | 202.48 | 81.55 | <.001 | .62 |
| | Δ F8 | 175.04 | 1 | 175.04 | 74.04 | <.001 | .60 |
| Groups | Δ F7 | 4.67 | 2 | 2.34 | 0.94 | .397 | .04 |
| | Δ F8 | 7.66 | 2 | 3.83 | 1.62 | .208 | .06 |

**Note.** *$p < .05$. $N = 53$.

A final MANOVA was conducted to investigate whether EEG power change scores during the GNG and baseline measures in F3 and F4 electrodes of the alpha band were significantly different when comparing the three groups. No significant differences between change in EEG power for any of the groups was found, supporting hypothesis 3b (Table 8.)

**Table 8.**

*Results of MANOVA for Comparing Frontal Power change of the alpha band during Go/No Go Task between ADHD and ODD symptomology, ADHD alone, and control groups*

| Source | Dependent Variable | Sum of Squares | *df* | Mean Square | F | *p* | Partial $\eta^2$ |
|---|---|---|---|---|---|---|---|
| Intercept | Δ F3 | .11 | 1 | .11 | 0.04 | .837 | .001 |
| | Δ F4 | .00 | 1 | .00 | .000 | .994 | .000 |
| Groups | Δ F3 | .52 | 2 | .26 | .100 | .905 | .004 |
| | Δ F4 | 3.37 | 2 | 1.68 | .583 | .562 | .023 |

**Note.** **p* < .05. *N* = 53.

## DISCUSSION

The aim of the current study was to determine associations between EEG and symptomology of ADHD, ODD, and executive functioning., as well as to examine the predictive power of change scores of EEG spectral power for symptomology of ADHD, ODD, and EF. Finally, this study aimed to compare groups' (ADHD+ODD, ADHD alone, HC) change scores of EEG spectral power during an attention, inhibition, and delay discounting task. Quantitative EEG spectral power across frequency bands have been extensively studied as possible biomarkers for ADHD and other disorders. Past literature has shown extensive results indicating significant differences in spectral power in the alpha frequency band and as a possible biomarker for individuals with ADHD (Adamou et al., 2020; Koehler et al., 2008). White et al. (2005) conducted a similar study finding increased alpha activity in individuals with ADHD during the attention task, consistent with Cowley et al.'s (2020) findings showing increased frontal and parietal pre-stimulus alpha during an inhibition and response task. Contrary to my hypothesis, I found no significant correlations between ADHD symptomology and change in EEG spectral

power due to the significant differences of spectral power for both an attention and inhibition task in past literature as noted above. This could be due to the newly implemented change scores, as past literature has only looked at spectral power in the alpha band during a baseline or attention task instead of subtracting them from one another.

While many studies have resulted in an increase in alpha power for individuals with ADHD, other studies have found a decreased power for fast frequency bands such as alpha (10-12Hz) for ADHD groups illustrating a dissonance in the field (Hasler et al., 2016; Woltering et al., 2012). Future research should analyze change in EEG spectral power for alpha frequency bands separating the low (8-10Hz) and high alpha band (10-12Hz) to determine if there is a difference as seen in past literature. Results indicated change in EEG spectral power of baseline eyes open and the attention task, specifically electrodes F3 and F4, and executive function composite scores were predictive of ADHD symptomology, which is consistent with past literature (Kiiski et al., 2020). The regression analyses indicated a positive relationship of the BRIEF-A scores and the F3 three electrode with ASRS scores, although the F4 electrode showed a negative relationship. These results indicate lower executive function abilities and increased change in spectral power for the F3 electrode predicted more ADHD symptomology consistent with past research indicating under activation in the left dlPFC for individuals with ADHD (Li et al., 2007; Rubia et al., 2008). Studies have also shown fractional anisotropy, which measures diffusion in the brain, in the left PFC is associated with greater symptom severity for individuals with ADHD (Silk et al., 2015).

While past literature has extensive findings for the association of the left PFC with ADHD symptomology, I also found a significant prediction of the ADHD symptomology with the F4 electrode indicating decreased change in spectral power for the F4 electrode predicts more

ADHD symptomology. Past research has long acknowledged the asymmetry of the PFC in both functional and structural resonance imaging in individuals with ADHD. He et al. (2021) conducted a meta-analysis where they found significant differences in structure and functional brain activity where increased asymmetry was associated with higher symptom severity. Asymmetry in the dlPFC has also been found to predict a higher number of commission errors throughout an inhibition task for children with ADHD (Ellis et al., 2017). These findings indicate the left and right brain contribute to different deficits of ADHD symptomology. Past literature has mainly focused on children when investigating asymmetry. This study illustrates the importance of continuing this work to adult samples to determine an explanation for the asymmetry. Dang et al. (2016) conducted a study which investigated asymmetry in adults with ADHD-like attentional symptoms. They found larger right compared to left caudate volumes were correlated with higher attentional and impulsivity symptoms as well as higher ADHD scores. These results support the overall agreement in the literature of ADHD presentation and symptomology changes as children develop into adulthood which could explain our findings of asymmetry. These findings as well as Popa et al.'s (2020) review article that discussed the role of quantitative EEG being used as additional information and insight to further determine if an in-depth clinical evaluation is needed for neuropsychiatric disorders, such as ADHD, instead of an immediate diagnostic tool should be kept in mind when using EEG as a possible biomarker too for ADHD.

The second hypothesis was supported when investigating the relationship between executive function, retrospective ODD symptoms and change in EEG spectral power scores. Correlations between the BRIEF-A and the retrospective ODBI were found to be positively correlated. This would indicate that lower executive functioning is associated with increased

ODD symptomology, consistent with past literature (Jiang et al., 2016; Schoorl et al., 2017). Regression analyses also supported my hypothesis indicating change in EEG scores for the F3 and F4 electrodes during the attention task do not predict ODD symptomology. These results were to be expected as past literature has shown activation in the prefrontal cortex, specifically electrodes F3 and F4, were only shown to be significantly different for the ADHD group alone without comorbid ODD (Rubia et al., 2008).

Rudo-Hutt (2015) conducted a meta-analysis of 62 studies indicating significantly higher delta and theta power as well as lower beta power for externalizing behaviors, a part of ODD symptomology. Future analyses with this dataset could determine change in power values associated with posterior temporal-parietal regions in these particular frequency bands as well. This result may also have occurred due to our measure asking for participants to remember ODD symptomology from when participants were a child, relying on their memory. Future directions should include longitudinal studies to implement a self-report and parent report for current ODD symptomology. Future studies could also implement a measure of self-reported CD symptomology as children with continuing ODD symptomology often receive a diagnosis of CD in adulthood, which could better indicate behavioral problems (APA, 2013).

To my knowledge, no research has been conducted comparing change in EEG spectral power between ADHD and comorbid ODD, ADHD alone, and a control group. Analyses showed no significant differences in change scores for spectral power of the alpha band for any of the groups during the attention, inhibition, or delay discounting task. These results were surprising as past research has indicated ADHD symptomology resulted in significantly different spectral power of the alpha band in adults with or without comorbid ODD (Rubia et al., 2008; Clarke et al., 2002). I also predicted the ADHD and comorbid ODD group compared to the ADHD only

group would not be significantly different consistent with past research findings indicating decreased alpha frequencies were only found for children with ADHD but not comorbid ODD, which was supported (Buyck & Wiersema, 2014). However, both the ADHD+ODD and ADHD showed no significant difference when compared with controls, which was surprising as past research has indicated individuals with ADHD found reduced activation in the left dlPFC during an inhibition task (Rubia et al., 2008), as well as less relative alpha and beta power in frontal regions compared to controls (Clarke et al, 2002). These results may be due to past research looking at resting state EEG spectral power in children instead of change scores in adults, as ODD is more prominently found in children (APA, 2013).

**Limitations**

The current study did have a few limitations. Little is known about the utility and meaning of change scores in spectral EEG power. My findings indicate change scores have significant predictive power which past literature has shown when comparing baseline and task spectral power. Determining if there is a difference between these different EEG measures should be the next step in differentiating the meaning of these findings from past literature. The sample size for comparing groups could have been increased as well as collecting data from a clinical or community sample to create more variability and an equal number between the three groups, which may have changed the results reported here. While the ODBI resulted in a reasonable Cronbach's alpha, a different measure for ODD symptomology could also assist in creating more equal groups as using a retrospective self-report is relying on memories, whereas using a measure associated with CD symptomology for current behavior problems. Conducting a longitudinal study with self-reports and parent-reports as children and then another self-report of

CD symptomology in adulthood would provide the developmental progression for symptomology of disruptive behaviors, including ODD and CD.

### Future Directions

Further research should be conducted looking at electrodes associated with the posterior temporal-parietal regions for ODD as reduced activation has been shown in these regions (Rubia et al., 2008). Further analyses should also be conducted to determine if the EEG spectral power for the baseline eyes open condition or the attention and inhibition task alone showed significant differences between groups in each of the tasks which would be more in line with past research (Debnath et al., 2021; Koehler et al., 2009). Groups were made based on self-reported scores for ADHD and ODD symptomology and executive functioning abilities. Due to different elevations, the groups were not equal in the number of participants, nor was demographic information matched between the groups. Therefore, when comparing the three groups, future studies should aim to increase the sample size to have equal group sizes and determine if change in EEG mean power is found to be significantly different. Future research should also aim to collect data in a clinical sample for ADHD and ODD symptomology as deficits may also be decreased in a college sample due to no inclusion criteria for a diagnosis being included in this study.

## CONCLUSION

This study showed BRIEF-A composite scores and change scores in EEG spectral power, specifically in the F3 and F4 electrodes in the alpha band, predicted ADHD symptomology using the ASRS. These findings indicate EEG change scores of the alpha band could be a possible biomarker for ADHD symptomology indicating further in-depth clinical testing to determine a possible ADHD diagnosis. The null findings also produced further research questions to

determine further differences in EEG activity when comparing ADHD and ODD symptomology as well as executive function abilities. This study is also one of the first to implement change scores as a measure of cognitive load and indicated their predictive ability. The validity and reliability of change scores should be continued to be investigated to determine their utility in research. Popa et al. (2020) also made an important distinction for EEG's predictive ability that should be kept in mind. While the majority of past research has looked at the utility of EEG brain activity as a biomarker and possible diagnostic agent, EEG might be beneficial to provide more insight such as other testing assessments to assist clinicians in making more informed diagnoses and reducing false positive and negatives.

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# Appendix A

## Adult ADHD Self-Report Scale (ASRS) – Concurrent Symptomology

### Adult ADHD Self-Report Scale (ASRS-v1.1) Symptom Checklist

| Patient Name | | Today's Date | | | | | |
|---|---|---|---|---|---|---|---|
| Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months. Please give this completed checklist to your healthcare professional to discuss during today's appointment. | | | Never | Rarely | Sometimes | Often | Very Often |
| 1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done? | | | | | | | |
| 2. How often do you have difficulty getting things in order when you have to do a task that requires organization? | | | | | | | |
| 3. How often do you have problems remembering appointments or obligations? | | | | | | | |
| 4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started? | | | | | | | |
| 5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time? | | | | | | | |
| 6. How often do you feel overly active and compelled to do things, like you were driven by a motor? | | | | | | | |
| | | | | | | | Part A |
| 7. How often do you make careless mistakes when you have to work on a boring or difficult project? | | | | | | | |
| 8. How often do you have difficulty keeping your attention when you are doing boring or repetitive work? | | | | | | | |
| 9. How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly? | | | | | | | |
| 10. How often do you misplace or have difficulty finding things at home or at work? | | | | | | | |
| 11. How often are you distracted by activity or noise around you? | | | | | | | |
| 12. How often do you leave your seat in meetings or other situations in which you are expected to remain seated? | | | | | | | |
| 13. How often do you feel restless or fidgety? | | | | | | | |
| 14. How often do you have difficulty unwinding and relaxing when you have time to yourself? | | | | | | | |
| 15. How often do you find yourself talking too much when you are in social situations? | | | | | | | |
| 16. When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves? | | | | | | | |
| 17. How often do you have difficulty waiting your turn in situations when turn taking is required? | | | | | | | |
| 18. How often do you interrupt others when they are busy? | | | | | | | |
| | | | | | | | Part B |

# Appendix B

## Oppositional Defiant Behavior Inventory (ODBI) Adapted – Retrospective Symptomology

This questionnaire asks you about your behavior as a child.

How often do you remember doing the following behaviors during your childhood (Age 8-10; Grade 3-5)? Check the most appropriate number.

| | Rarely | Sometimes | Often | Always |
|---|---|---|---|---|
| | Once a month or less | Once a week | 2-3 times a week | 4 times a week or more |
| 1. Had temper tantrums when things did not go as you wished. | 0 | 1 | 2 | 3 |
| 2. Talked back when you were warned. | 0 | 1 | 2 | 3 |
| 3. Did not obey adults. | 0 | 1 | 2 | 3 |
| 4. Deliberately did things that others disliked. | 0 | 1 | 2 | 3 |
| 5. Blamed your failure on someone else | 0 | 1 | 2 | 3 |
| 6. Misinterpreted words or situations and became sulky. | 0 | 1 | 2 | 3 |
| 7. Did mean things to siblings and friends. | 0 | 1 | 2 | 3 |
| 8. Talked back when your thoughts or behaviors were denied. | 0 | 1 | 2 | 3 |
| 9. Made fools of siblings and friends. | 0 | 1 | 2 | 3 |
| 10. Felt inferior and got annoyed. | 0 | 1 | 2 | 3 |
| 11. Got upset when warned. | 0 | 1 | 2 | 3 |
| 12. Had temper tantrums when treated unkindly. | 0 | 1 | 2 | 3 |
| 13. Insisted on your demands being accepted. | 0 | 1 | 2 | 3 |
| 14. Interrupted others. | 0 | 1 | 2 | 3 |
| 15. Did not apologize when you were to blame. | 0 | 1 | 2 | 3 |
| 16. Got annoyed when things did not go as you wished. | 0 | 1 | 2 | 3 |
| 17. Got upset when things were not to your liking. | 0 | 1 | 2 | 3 |
| 18. Grumbled at people. | 0 | 1 | 2 | 3 |

# Appendix C

## Calculate Mean EEG Power Script

pop_spectopo_script_mean_power.m

```
%% Trying "channel spectra and maps" to get plots

sampRate = 500; %sampling rate of your data
lowerFreq = 8; %lower bound of your frequency band of interest
higherFreq = 12; %upper bound of your frequency band
chanNr = 3; %channel number of your lead; have to put number in
%and not letter name of channel
%computing log spectrum for different frequencies
[power, freq] = spectopo(EEG.data(chanNr, :), 0, sampRate);
%average power within the predefined frequency range
meanPower = mean(power(freq>= lowerFreq & freq <= higherFreq));
disp(meanPower);

%% channels that we want to get mean power for legend

%F3 = 3
%F4 = 29
%F7 = 4
%F8 = 30
%T7 = 9
%T8 = 25
%P7 = 15
%P8 = 20
%C3 = 8
%C4 = 24
```

# Appendix D

## Thesis EEG Cleaning Protocol

AOEE EEG Cleaning Protocol

EEG Brain Vision Cleaning for Baseline, Power mean of 8-12Hz

**Uploading Brain Vision Data into EEGLAB**

1. Download MATLAB and EEGlab function
   - **Make sure EEGlab folder is in MATLAB folder**
2. Download the cleanline pipeline compressed folder from the link below to your computer and put it in your EEGLAB folder
   - https://www.nitrc.org/projects/cleanline
3. Bring up MATLAB and go into EEGlab folder on left "current folder" column
4. Type in eeglab in the command window and it will bring up your EEGlab

**Import Brain Vision Data**

1. In your EEGlab window, go to File -> import data -> manage EEGlab extensions
2. Install bva-io v1.7 extension to import Brain Vision Analyser data files
3. To import data, go to File -> import data -> Using EEGLAB functions and plugins -> From Brain Vis. Rec. .vhdr or .ahdr file
4. It will bring up a browsing window to look through your files. Find your .vhdr file and open it.
   - This window comes up. For "interval", enter "all?". For "channel", enter "all?".
   - It will then ask you to name your file. Here I named it "Test_Protocol" to show what pops up after in the EEGLAB window.

**BEFORE CLEANING:**

****YOU SHOULD HAVE AN EXCEL DOCUMENT WITH FILE NAME AND WHAT YOU DID TO THE FILE WHILE CLEANING AS YOU GO ALONG**

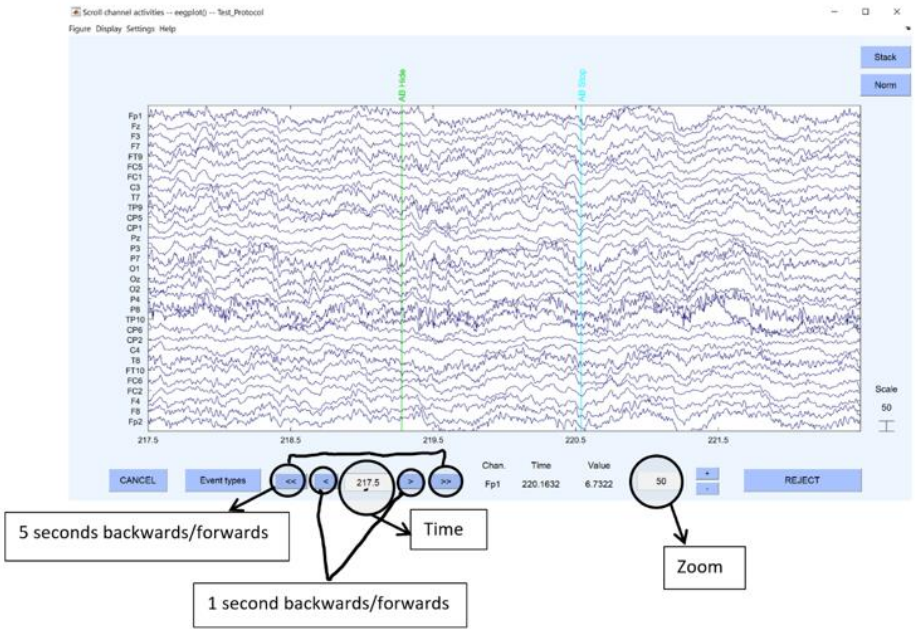
- Examples:
  - What ICA components you reject
  - How much data you reject if you need to
  - Any electrodes you interpolated

**NOTE:**

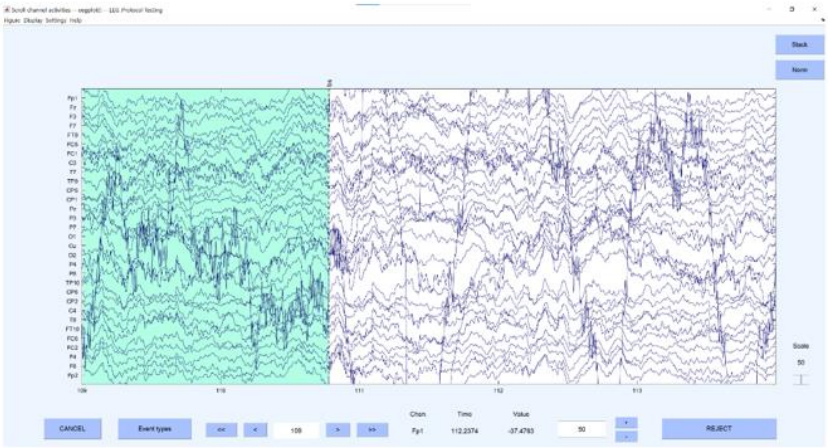
- ***Can also interpolate electrodes before separating the tasks so you don't have to interpolate every time (step by step is after ICAs)**

**Rejecting Data between Tasks**

1. In the window above after importing data, go to Plot -> channel data (scroll)
   - You can see in the picture below the brain waves and the AB task currently showing.
   - Make sure your "Zoom value" is at "50".




2. Find the “bs” to the “x”. (Be careful in finding the x as every task ends with x.)
3. Click on the waves at the “bs” line, hold your mouse down and the waves will highlight green.
    - Make sure you do not click back on the green highlighted or you will erase the highlight. Highlight everything before and after the x.
4. Click the Reject button when you have all data in between tasks and anything super noisy during task highlighted.

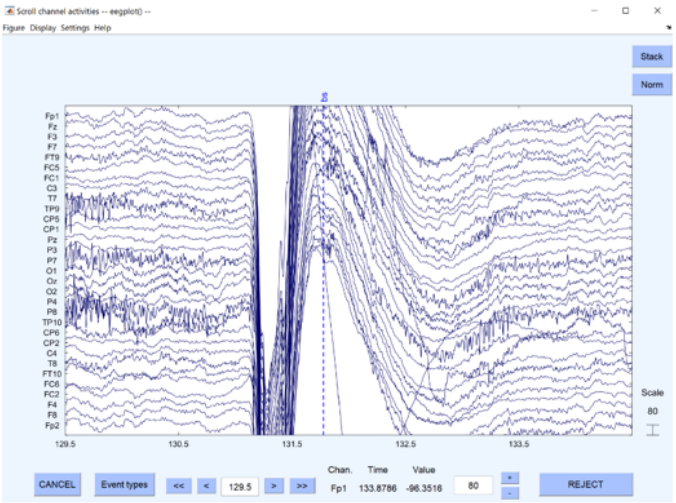



5. After rejecting, it will ask you to save as. Make sure to save as so you have your original file and make a new one with the cleaned version of just the baseline.

- Make sure to check the “save it as file” in the top half under “name it”. Browse your computer and put it in the folder you choose. Then name it whatever you want. I would name it AOEE_2001_cleanline_rejected.

**Rejecting Noisy Data (can do this step when you are rejecting between tasks in step above too)**

- Example of what to reject:




- To reject:
- Scroll through all the waves of the task and highlight all parts you want to reject. Another example:
- Once all parts are highlighted to delete, hit the “reject” button in the bottom right corner from the screenshot above.
- Save as file in the window above.
    - I named the file above for participant, ran through cleanline, rejected to only SM Show task, run through ICA, and rejected noise as shown above.

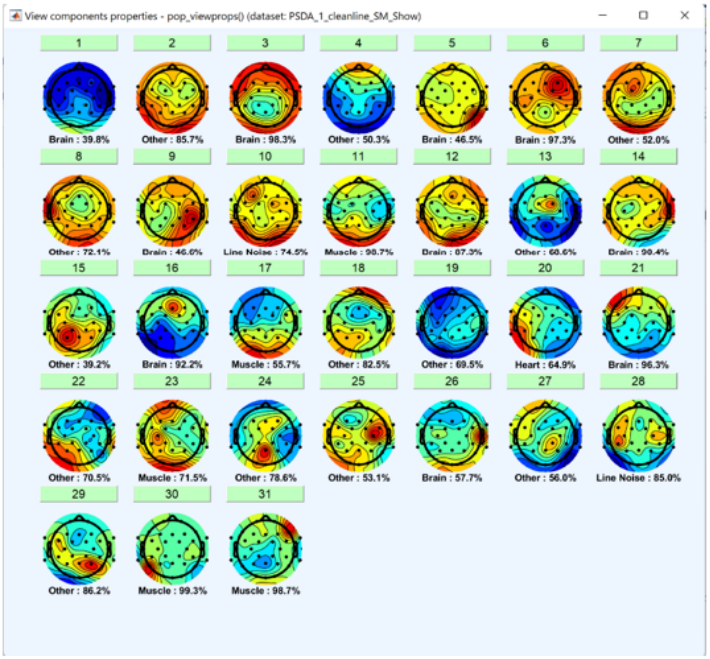
**Cleaning with Cleanline Pipeline**

1. Make sure to go to cleanline online and download the compressed zip folder.
2. Once it is downloaded, be sure to put the file into your EEGLAB file that is part of MATLAB
3. Load EEGLAB into your Matlab window to get this popup:
4. If data is not already imported, follow the steps to import above.
5. Once you are here, go to tools -> cleanline (at the bottom of the menu and you will get this window)
6. You should not have to change anything, and click ok
7. In the command window, if the pipeline is working you should see something like this:
8. Once it is done cleaning you should get this popup:

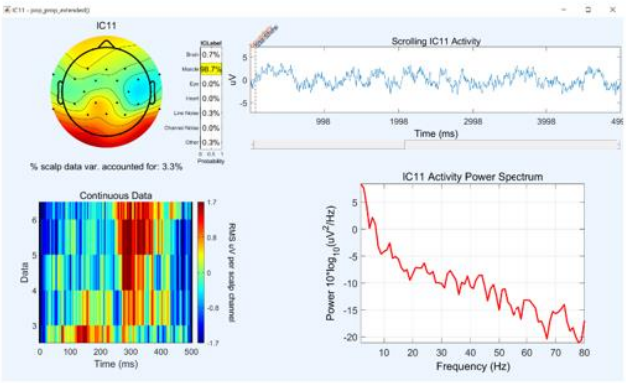
9. It should popup with only the name of the file "AOEE_2001" and then I would add "_cleanline" as the picture shows and save as the file in the place you want it to have the original file and have the data that is cleaned through cleanline as well

**Running ICAs**

- Tools -> Decompose Data by ICA -> the following popup will appear -> click "ok" without changing anything
- The following window should pop up. DON'T INTERRUPT.
- Your command window should look something like this. You will see the "done" at the bottom when finished and the interrupt window should go away.
- Once ICA is run go back to Tools -> Classify components using IC Label -> label components
- This window will pop up and you should click "ok"
- Click "ok" here as well
- The following window should start loading:

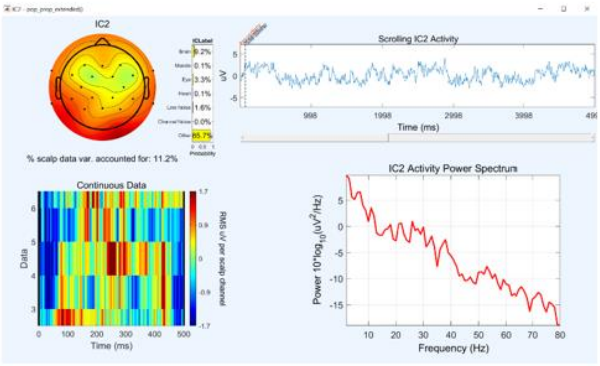



- To start rejecting components, look through each number. Pay specific attention to the ones with noise above 50% (not brain activity). For example, 2, 4, 7, 8, 10, 11, 13, 17, 18, 19, 20, 22, 23, 24, 25, 27, 28, 29, 30, 31. (Examples are only to look at. Shouldn't get rid of all of them)
- Example of one to get rid of:
    - Shows muscle to be 98% and brain is not even 1%. You should get rid of component 11




**NOTE:** you should look through **ALL** components but if there is any sort of brain activity for the component you should leave it due to little data after rejecting to only one task

- Example:




- Other is ranked at 85% but brain shows 9% so you should not get rid of component 2

**To get rid of ICA components**

- After looking through all 31 components...
- Go back to EEGLab window (you do not have to exit out of the 31 components window)
- Tools -> remove components from data -> this window should pop up
- List in the components to remove data which components **YOU HAVE WRITTEN DOWN IN YOUR EXCEL SHEET** to get rid of
- Possible examples from the list above could be:
- Click “ok”. None of these components should have any brain activity when you are looking through the components
- This should pop up after clicking ok and if you have all the right components you should click “accept”
- This should popup after accepting. Rename file and “save it as file” so you aren’t saving over the AOEE_2001_cleanline_bs file.

- I would name it "AOEE_2001_cleanline_rejected_ICA" to show participant name, ran through cleanline, rejected to only show tasks, and ran through the ICA

****NOTE*****

- *****You might want to interpolate channels if that is what is making your data noisy. If you think your data will look better and the only noise is coming from one channel, complete the interpolating steps before rejecting any time points of data.**
- *****Can also interpolate before separating the tasks so you don't have to interpolate every time**
- When rejecting data to have just the baseline, make sure you are cleaning any data inside the baseline for really noisy data. (You will highlight those time points if needed and reject them when you reject the other tasks)

**Interpolating specific channels that have bad noise**

1. After saving the baseline, your EEGLAB window will bring up the name that you saved it as. In this case, I saved mine as PSDA6_bs. (You can name yours whatever you want as long as you know what it stands for.)
2. To interpolate electrodes, as you can see in the above data, there is one wave going crazy. This electrode is TP10. Make sure to find the electrode that you want to interpolate.
   - Example of one single electrode that looks noisy to be interpolated.
3. Go to the EEGLAB window, go to tools -> interpolate electrodes.
4. Select "select from data channels". It takes you to a window with all electrodes.
5. Select the electrode that you want. And click ok. It will then take you back to the previous window and you will again click ok.
6. Go back to plot -> channel data (scroll). You then see TP10 much more calm and not as noisy.

- After interpolating, the save as window should pop up:
  - File name shows participant #, ran through cleanline, rejected to only show task SM Show, ran through ICA, rejected any noisy segments, and interpolated TP10
  - **NOTE:** if interpolated multiple electrodes just name it "int_TP10_O2_next electrode"

**Segmenting Data Into tasks**

1. Find task markers as shown above with "bs" and then find the "x" that ends the task
2. Reject everything before and after the bs and x to only have data for baseline.
3. Repeat this step for all tasks in the dataset.
   a. Bso to x
   b. Bsc to x
   c. Bsv to x
   d. ANT1 to x, ANT2 to x, ANT3 to x
   e. GNG to x
   f. 5DD to x
4. Save datasets as to their own file: "AOEE_2001_rejected_cleanline_ICA_bso"
   a. Change the highlighted part as needed based on what task you are on

**Finding the power mean**

1. Open up the “pop_spectopo_script_mean_power.m” script
2. Sampling rate can be found in the EEGLAB window.
3. Frequency is the frequency band you are interested in. In this case, we are looking into the alpha frequency, so we plug in 6-9Hz.
4. The channel number is based off of the head scalp map.
    - To find the channel locations, go to the EEGLAB window. Go to plot -> channel locations -> and you can choose by name or by number shown below.
    - We are interested in F3, F4, F7, F8, T7, and T8.
    - The script has a legend to show what numbers are for each channel location as the script requires you to use the number form. You can also look where F3 is located on the head map above and see it is 3 in the number channel location.

**NOTE**

- Make sure to notice that although F3 lines up with being #3, but not all of them are like that case. Electrode F4 lines up to be channel 29 so it does not line up with the number after the letter.

5. Finally, after plugging in all of the numbers, click into the script to where your cursor is in the top yellow highlighted part and click “control enter” on windows or highlight the correct part and click the green run arrow shown below.
    - You see above the top part of the script is highlighted yellow. Make sure that is highlighted and click the green play button that says “run” circled in the picture or “control enter”.
6. After running the script, you will see the command window below giving you the mean power and a figure.