ADHD AND COGNITIVE FUNCTIONING: MULTI-MEDIATION BY PERSONALITY AND BEHAVIORAL VARIABILITY

By

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A thesis submitted to the faculty of Radford University
in partial fulfillment of the requirements for the degree of
Master of Arts in the Department of Psychology

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April 2012

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ABSTRACT

In statistical tests involving data in a time-series, proportions of variability accounted for by anything other than the proposed instrument of measurement is thought to be random. Previously obtained results acquired through spectral analysis have suggested that there is actually a systematic pattern within the data. This study investigates the possibility of this pattern of results being a mediator, between the relationship between ADHD and cognitive functioning. Personality is also hypothesized to be a second mediator between these variables, following relationships found in previous literature. 79 undergraduate students participated in this study of multi-mediation to assess their ADHD, personality, and cognitive performance scores. Spectral analysis is used to detect whether periodic patterns are present in the time-series residuals, and the spectral density slope calculated indicates the presence of “pink noise”. This result supports previous findings on systematic cyclical behavior in time-series analysis. Correlational analyses reveal relationships between the spectral density slope and the discussed variables. Interestingly, correlational analyses found no greater number of significant relationships between ADHD variables and cognitive performance variables than would be found by chance alone, thus nullifying the need for a mediation test. Personality variables held significant relationships with ADHD, as found in previous studies. Personality also had a significant relationship with cognitive performance. Strengths and limitations of the results of the study are discussed in detail.

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DEDICATION

I dedicate this work to my mother, Cynthia Preston, and father, Jon Frum. They have taught me that any goal and any success can be achieved with enough patience and hard work. It simply takes one step at a time, regardless of the size of the step. Each individual step is a journey unlike any other step.

ACKNOWLEDGEMENTS

I would like to thank Dr. Thomas Pierce for his tireless mentorship during this process. Under his guidance, another research step has been taken, and leads to more exciting directions. Thank you for introducing spectral analysis and the concept of pink noise. This has been an interesting step for knowledge and the results are thanks to your support and assistance.

I would also like to thank Dr. Jeffery Aspelmeier, Dr. Ruth Riding-Malon, and Dr. Joseph King for serving on my thesis committee. Each person has provided their expertise and insight into this work. It has been a great privilege to work with amazing minds in the field of Psychology.

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CHAPTER 1: DESCRIBING TIME-SERIES ANALYSIS

ADHD is a neurobehavioral disorder found in both adults and children that is commonly characterized by levels of inattentiveness, impulsivity, and hyperactivity that is well beyond the normal range for a person's development. More importantly, it is associated with lower levels of performance in a number of areas of cognitive functioning, including executive functioning (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Barkley, 1997). In other domains of functioning, preadolescent girls with ADHD have displayed patterns of dysfunction in the form of poor academic performance and social isolation from their peers (Hinshaw, 2002). Even adults with ADHD show lower performance in verbal and visual memory tests compared to control groups (Muller et al., 2007). ADHD has a worldwide prevalence of roughly 6 percent (Biederman, 2008) and roughly 4 percent within the United States (Kessler et al., 2006).

One feature of task performance displayed by participants with ADHD is the highly variable nature of the scores they provide across trials. One method for assessing this variability is by obtaining the standard deviation of these scores. Individuals with ADHD often have higher standard deviations in the scores they provide, such as in tasks involving reaction times (e.g., go-no/go tasks, choice discrimination tasks, etc.; Epstein et al., 2011). An alternative approach to quantifying the variability of performance across trials is through a technique known as spectral analysis.

Spectral Analysis of Time-series Data

In statistical tests used to address research questions involving reaction time data, relatively small proportions of the variability in a data set are accounted for by manipulations of the experimental conditions. The residual unaccounted-for variance is assumed to be random and is often ignored (Thornton & Gilden, 2005). This background variance is sometimes referred to as “error” or “noise”, and typically accounts for a substantial amount of variability in the scores provided. When examining a graph of residuals of reaction times, any systematic patterns reflect changes in behavior over time that is unrelated to the task condition on each trial. This record of changing responses takes the form of a highly complex waveform. Figure 1 displays a sample graph of residuals obtained from a two-choice reaction time task.

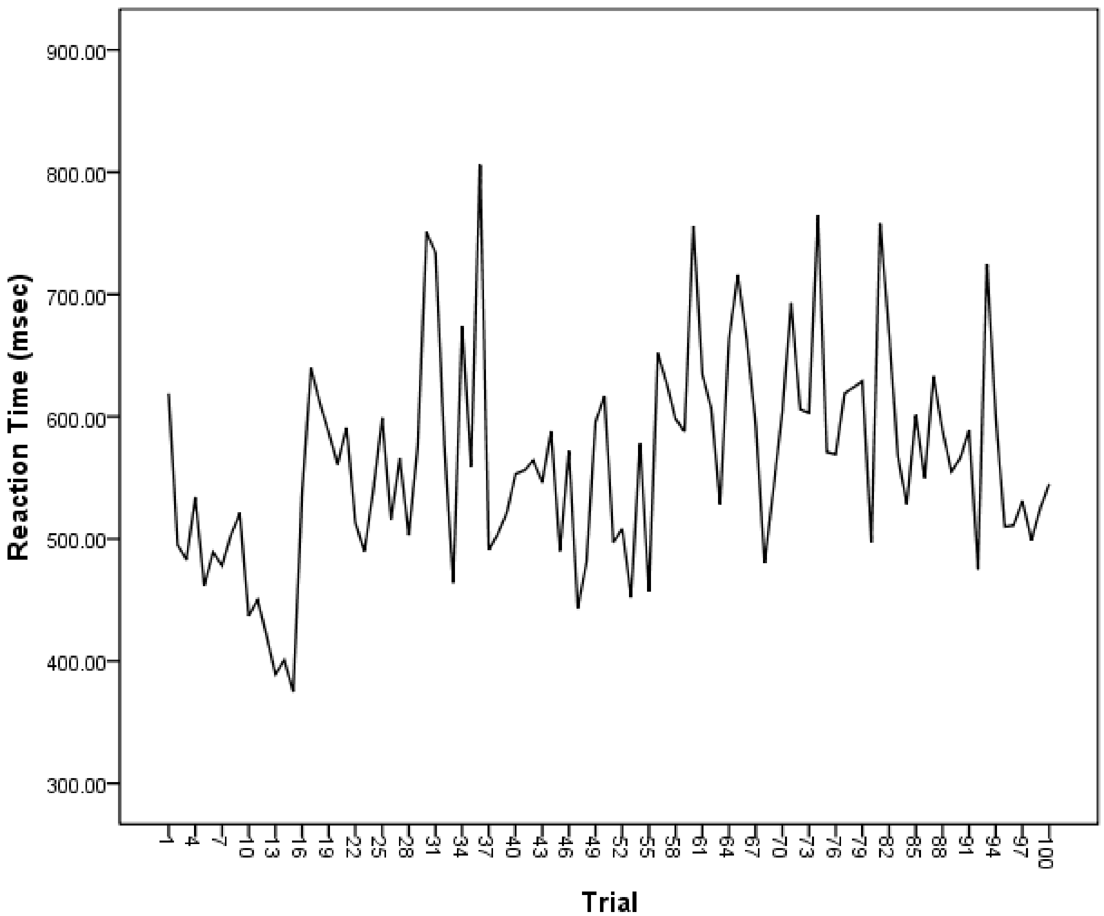

Figure 1. Sample graph of reaction time residuals. Any pattern of variability in the curve that is not accounted for by the task would reflect noise, often thought to be random (Frum & Pierce, 2011a).

In 1830, Jean Joseph Fourier showed that any complex waveform can be described as a combination of simpler sine waves (Williams, 1997). A *cycle* of performance is a complete wave (i.e., peak to peak), which repeats itself across time. A sine wave's *period* represents the time needed for one complete cycle. The *frequency* of a sine wave represents the number of cycles per unit of time. A biologically-based signal, such as EEG, can therefore be represented by a combination of sine waves, each with a specific frequency. Graphs of both a sine wave and a sample of EEG data are presented in Figure 2.

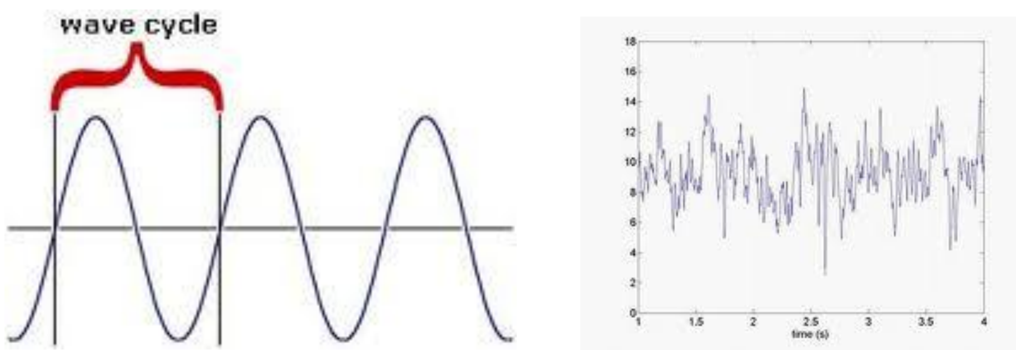

Figure 2. Sine Wave (left) vs. EEG wave (right). Any complex wave such as the EEG can be broken down into simpler sine waves, each with a specific frequency (Anaya, 2009).

A sine wave with a specific frequency and amplitude can be extracted from the more complex waveform, thus capturing a portion of the total variance in the complex waveform associated with this frequency. The variance accounted for by a sine wave oscillating at this particular frequency is known as the *power* of that frequency. Sine waves with different periods can capture different proportions of the total variance among the scores. Spectral analysis identifies the power or variance that is attributed to each frequency that is present in the original waveform (Williams, 1997). The residuals within a behavioral waveform will create different patterns based on the profile of variances explained by each frequency. A *periodogram*, the most common way of displaying the results of the spectral analysis, shows the relationship between the frequencies that could be present in the original waveform and the power or variance associated with each frequency. The top graph of Figure 3 shows this relationship in its original units, with frequency on the x-axis and power on the y-axis.

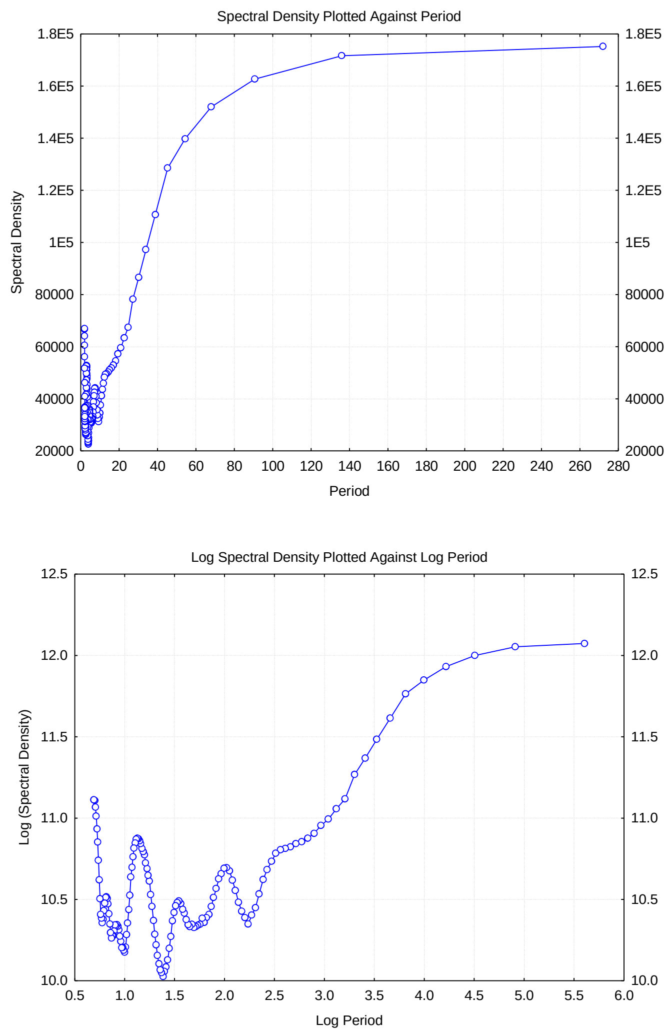

Figure 3. Power/Frequency relationship. These are displayed in non-log (top) and log-log units. The bottom graph is the result of a smoothed spectral density curve (Frum & Pierce, 2011).

The original periodogram is typically transformed into a curve that more closely resembles a straight line. This *power spectral density curve* is displayed as a log-log plot, in which the log of density (e.g., power) is plotted against the log of frequency (See the bottom graph of Figure 3). The slope of that line determines the calculated change in the log of power per unit change in the log of frequency. The relationship between frequency and power can be expressed by the relationship Power = 1/frequency^x, in which x represents the slope of the line of the log-log plot. The slope of the regression line of the log-log plot of frequency and power is thus a highly useful and simple way of quantifying the profile of frequencies present in a complex waveform, with the exponent of frequency signifying the "color" of the noise. The varying colors of noise each have a unique degree of complexity, describing a different pattern of change in the behavior of interest.

White noise (See Figure 4) is completely random, uncorrelated noise, such as the static generated by an electronic device. Considered to be the most complex form of noise, it is characterized by a slope of the log-log plots approximately equal to zero. The equation for white noise is thus, power = $1/f^0$.

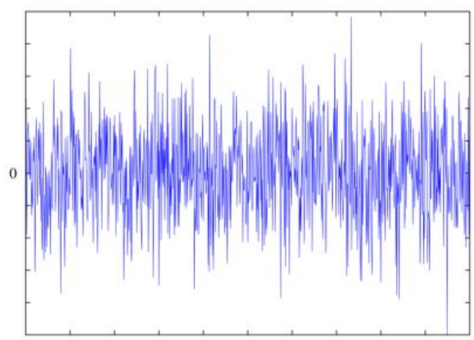

Figure 4. Graph of White Noise. This form of noise occurs when the power is equally distributed across all known frequencies in a complex curve (White Noise, 2008).

Pink noise (See Figure 5), also known as 1/f noise ($1/f^1$), is considered a midpoint of complexity between maximally complex white noise and a pattern in which a score at one point in time can be predicted perfectly by the score that came just before it. This pattern represents an intermediate state in terms of randomness, predictability, and order (Thornton & Gilden, 2005). This type of noise is characterized by a slope of log-log plots equal to -1. Typically, a 1/f time series has more power in the slower frequencies than in the higher frequencies. Figure 5 displays a sample power spectral density plot with a slope approximately equal to -1. 1/f noise has been documented in a variety of fields, including torsion forces in physics (Bak, Tang, & Wiesenfeld, 1987), human cognition (Gilden, Thornton, & Mallon, 1995), Earth systems in geology (Plotnick, 2003), and heart rate variability (Sarlis, Skordas, & Varotsos, 2009). Although 1/f noise is commonly observed in nature, the origination of and meaning behind this pattern is highly controversial (Gilden, Thornton, and Mallon, 1995).

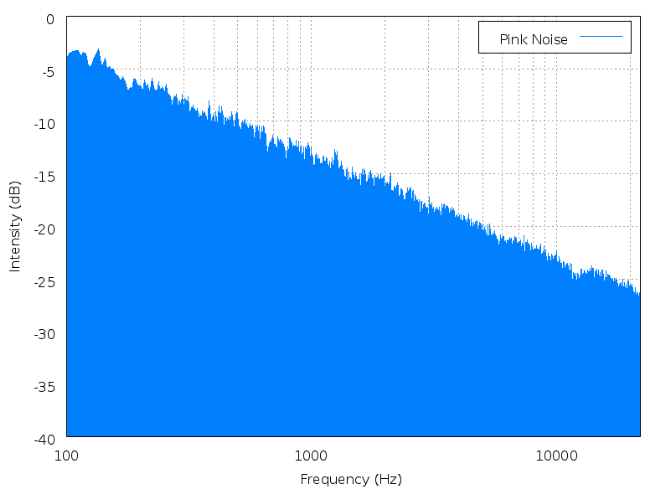

Figure 5. Spectral Density Plot of 1/f (Pink) Noise. This particular example reflects a pattern in which slower frequencies contain more power than faster frequencies (Pink Noise Spectrum, 2006).

Brown noise, known as “random walk” or $1/f^2$ noise, occurs when the data points are strongly correlated to each other, exhibiting a pattern with less complexity than observed with pink (1/f) noise. Also known in physics as Brownian motion, this pattern of behavior is associated with higher levels of predictability of a single point in a time-series than either pink or white noise. In brown noise, the slope of log-log plots is -2. The power is inversely proportional to frequency squared, $1/f^2$. Figure 6 displays a brown noise time series on the right and the power spectral density plot for these data, with a slope approximately equal to -2.

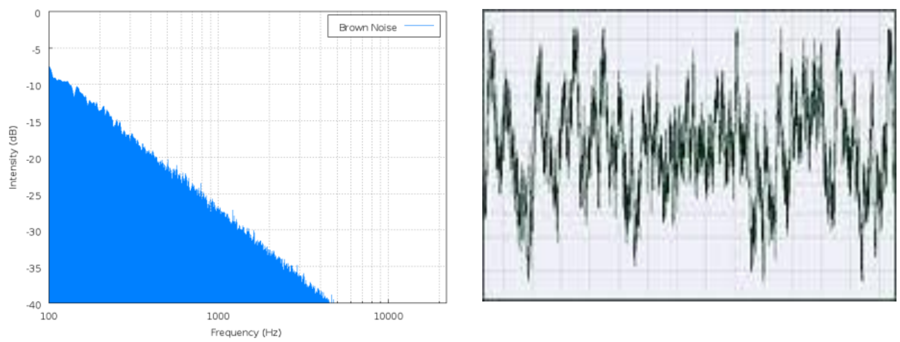

Figure 6. Example of Brown Noise, slope = -2. The left graph represents a spectral density plot with more power in slower frequencies than faster frequencies in the curve. The right graph represents the complex wave prior to being smoothed into a periodogram (Brown Noise Spectrum, 2006).

Spectral Density Analysis in Human Cognition

A number of studies have conducted power spectral analyses on reaction time data (Gilden, 2001; Gilden and Handcock, 2007; Gilden, Thornton & Mallon, 1995; Thornton & Gilden, 2005). Although there is no established meaning behind 1/f noise, it is widely recognized that it represents the presence of a complex pattern of change over time in situations where no pattern was thought to exist (Correll, 2008, Gilden, Thornton, & Mallon, 1995). For example, Gilden and Hancock (2007) conducted a spectral analysis on data from a 480 trial mental rotation task for participants with and without a diagnosis of ADHD. The mean slope of spectral density regression lines for ADHD participants was significantly steeper than those of non-ADHD participants. The researchers suggested that the pattern produced by ADHD participants was similar to pink noise, with traces of random walk included, resulting in a mean slope of 1.6.

A pilot study conducted in Spring 2011 by the author obtained power spectral density curves from 31 undergraduate students. Using a 110 trial choice reaction time task, the results showed that the mean slope of the log-log plots was significantly different from white noise, but the slope of the regression line was not steep enough to classify as 1/f (pink) noise. Rather, the slope of the spectral density curve corresponded to what might be referred to as a "light pink" noise, with a mean slope of .23. Twopossibilities for the vast difference in mean slopes were due to the difference in task, as well as the difference in the length of task.

In addition, correlational analyses revealed a significant relationship between the slope of power spectral density regression lines and higher scores on the Conners Adult ADHD Rating Scale (Frum & Pierce, 2011). Persons with steeper slopes of the regression line were more likely to have higher total ADHD scores and higher scores of impulsivity and hyperactivity. One possible explanation for the difference in slope values between the pilot study and Gilden and Hancock's study (2007) is the difference in tasks used. It may also be that using a shorter task produces spectral density plots that are less similar to 1/f noise and more similar to white noise because of the reduced demands on cognitive resources over time. With regard to ADHD, the overall pattern observed in the pilot study was the same as that reported by Gilden et al. (2007).

CHAPTER 2: RELATIONSHIPS BETWEEN MEDIATING VARIABLES

ADHD and Personality Variables

In addition to the more highly variable behavioral responses associated with ADHD, persons with ADHD have also been found to differ from non-ADHD participants in terms of a number of personality variables. Co-morbidity is common in people with ADHD, and a diagnosis of ADHD is often seen in conjunction with other psychiatric disorders linked to one's personality. For example, Jacob et al. (2007) examined the co-morbidity of Adult ADHD and relevant disorders, with a focus on mood and personality traits. They found strong squared correlations between ADHD and DSM-IV criteria axis-II disorders, including .573 with mood disorders, .272 with anxiety disorders, and with squared correlations ranging from .12 to .35 with paranoid, histrionic, and avoidant personality disorder clusters.

In addition to association with a number of psychiatric conditions, several aspects of personality have been linked to symptoms of ADHD in children and teenagers. For example, Jacob et al. (2007) found that adult ADHD patients had higher Neuroticism scores on the NEO-PI-R inventory, and lower Extraversion, Openness, and Conscientiousness scores. However, all subscales of the Five Factor Model of personality appear to account for significant proportions of variability in measures of inattention, hyperactivity or impulsivity, and overall raw scores on behavioral tests for ADHD (Parker, Majeski, & Collin, 2003).

Parker et al. (2003) state that hyper-responsiveness is a common feature of ADHD, which accounts for the wide variety of studies examining Neuroticism and Extraversion. A study was conducted on undergraduate psychology students using the

Conners Adult ADHD Rating Scale and the NEO Five Factor Inventory. Inattentiveness was significantly correlated with Neuroticism, Openness, and Conscientiousness, while hyperactivity was significantly correlated with all subscales except Openness (Parker et al., 2003). Significant correlations were found with all subscales and total ADHD scores.

For adults, Openness has been significantly linked with higher scores of general cognition, memory, and speed of information processing, while Extraversion scores are negatively linked with those same categories (Soubelet & Salthouse, 2011). Openness was once thought to represent intellect, but the authors believe that extraverts tend to veer more towards abstract intellectual thinking than generalized intellectual thinking. For example, Moutafi, Furnham, & Paltiel (2005) discovered a significant relationship between general intelligence and Extraversion, Conscientiousness, and Neuroticism, with the combined variables accounting for 13% of the total variability. However, some researchers have argued that personality may be a poor predictor of intelligence or cognition (Soubelet & Salthouse, 2011). It may be that only some aspects of personality are related to cognitive functioning.

1/f Noise and Personality

No research has been published that describes a relationship between 1/f noise and personality. However, because there is such a strong correlation between a number of personality variables and ADHD, it is reasonable to assume that relationships also exist between personality variables and the slope of power spectral density curves. Based on the literature discussing the strong correlations between ADHD and personality, it is hypothesized that participants who have high scores on measures of Neuroticism and/or Extraversion will most likely generate 1/f noise, while participants with low scores in these subtypes will most likely generate white noise. The pilot study showed a significant relationship between the power spectrum density slope and measures of personality. The mean slope of the regression line accounted for approximately 30 percent of the average variability of personality scores (Frum & Pierce, 2011). Notably, scores on Openness did not significantly correlate with the slope measure, so it is unclear how strong an association exists between this particular personality variable and cognitive function.

Although there is no clear explanation as to why the presence of ADHD should be associated with higher or lower scores on personality variables, it appears that individuals who have moderate to high degrees of neuroticism are more likely to display behavior consistent with ADHD. Additionally, extraverts are more likely to display impulsive behaviors than introverts (Parker et al., 2003), providing further support for the presence of a relationship between personality variables and cognitive function.

Present Study and Hypotheses

The purpose of this study was to determine whether (a) the spectral density of residual reaction time performance over time and/or (b) personality variables at least partially mediate relationships between ADHD status and the residuals of working memory reaction time data. The present study collected data regarding the Big-Five personality factors through use of the International Personality Item Pool (IPIP; Goldberg et al., 2006), and self-report rating scores of ADHD as described by the DSM-IV-TR (Allpsych, 2002) through the Connors Adult ADHD Rating Scale (CAARS; Pearson, 2011). It also measured cognitive function through performance on the Intermediate Visual and Audio Continuous Performance Test (IVA; IPS, 2005) and spectral density of performance on the Sternberg capacity of working memory reaction time task (Sternberg, 1966). The method of assessment for ADHD subscales of impulsivity, inattention, and hyperactivity was measured by the CAARS.

Figure 7 illustrates the proposed model tested. ADHD variables, as assessed by the CAARS, are hypothesized to have a direct effect of measures on cognitive function obtained from the IVA task. Based on previous literature, it was anticipated that there would be a significant relationship between self-report scores of ADHD and cognitive functioning. In addition, it was predicted that there would be significant relationships between ADHD and behavioral variability, and between behavioral variability and cognitive performance. Assuming such relationships exist, it was hypothesized that the calculated power spectral density slope would serve as at least a partial mediator between scores of ADHD and cognitive functioning.

Following the literature, it was predicted that there would be a significant relationship between ADHD scores and personality scores. It was also hypothesized that personality scores would also have a significant relationship with cognitive functioning. Based on these predictions, it was hypothesized that personality would serve as at least a partial mediator between scores of ADHD and cognitive functioning.

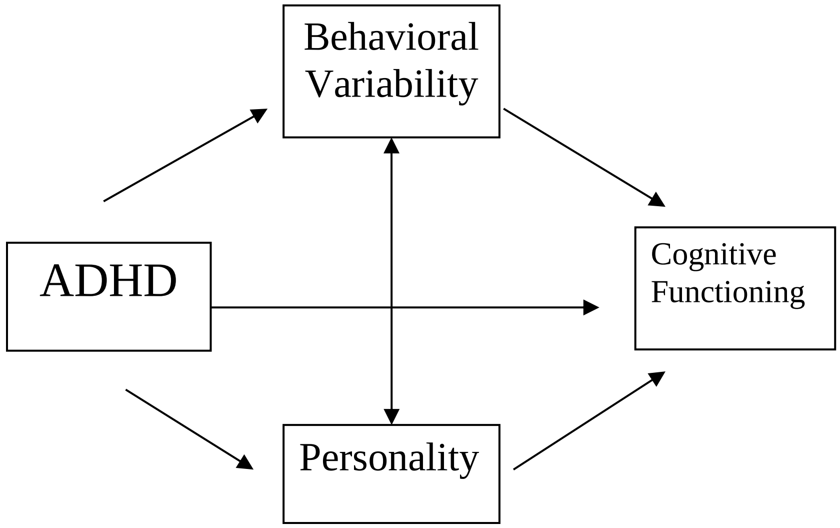

Figure 7. Proposed Model of Multi-Mediation. The primary hypothesis centered on a significant relationship between ADHD and Cognitive Functioning. Behavioral Variability (Noise) and Personality would serve as the proposed mediators of this hypothesis.

Based on the model outlined above, the primary contributions of the present study are that it (a) would assess the presence of a relationship between personality scores and 1/f noise, and (b) examine the mediation effects of behavioral variability and personality scores between ADHD and cognitive performance. Because previous research has shown significant relationships between behavioral variability and ADHD, as well as between personality and ADHD, it was hypothesized that the calculated power-spectrum slopes would be partial mediators.

Baron and Kenny's (1986) method for determining the presence of a mediation effect would be used to test the major predications that both behavioral variability and personality variables mediate the relationships between ADHD and cognitive function. Hierarchical regression would also be used to determine whether behavioral variability or personality variables are the stronger predictors of cognitive function. It was predicted that both sets of variables would account for significant proportions of variability beyond the influences of the other variable.

CHAPTER 3: METHOD

Participants

Undergraduate participants were recruited using the Psychology Department's SONA research participation software to allow them to voluntarily sign up for the experiment. By electing to participate in the study, they received credit through SONA, through which they received course credit as determined by the participants' instructors. Anticipating correlations among study variables of .3, it was necessary to recruit 79 participants to achieve values of approximately .90 for statistical power. Participant ages ranged between 18-41 years with the mean age being 19.46 (*SD* = 3.475) There were 22 males and 57 females in this study, and "Caucasian" was the most commonly reported race, with 72 respondents.

Materials

Materials used in this study consisted of a demographics questionnaire, the International Personality Item Pool (IPIP) Big-Five Factor 50 item questionnaire, and the Conners Adult ADHD Rating Scale (CAARS) for personality and ADHD assessment, which was administered to each participant on paper. There were also the Intermediate Visual and Auditory Continuous Performance Test (IVA) software and a working memory task. Each participant completed these tasks on the computer.

Demographics

The demographics questionnaire consisted of approximately 15 questions, collecting descriptive information about each participant, including information about age, gender, ethnicity, handedness, medication taken, average caffeine intake and caffeine consumed the night before examination, hours of sleep daily and amount of sleep received the night before testing, and education level (see Appendix A). It also included questions regarding participants' ADHD status, including medications currently or previously taken. This questionnaire took approximately 5 minutes to complete.

International Personality Item Pool

The IPIP Big-Five Factor questionnaire is comprised of 50 items addressing 5 major constructs of personality, specifically those addressed in the Big Five Factor inventories (Neuroticism, Extraversion, Openness to experience, Agreeableness, and Conscientiousness; Goldberg, 1999). For this particular questionnaire, the construct of neuroticism is referred to as Emotional Stability, and openness is referred to as Intellect/Imagination (see Appendix B). The IPIP Big-Five Factor items are displayed as statements, each meant to assess one of the five personality constructs, using a 5-point rating scale. Each statements' response options range from Very Inaccurate to Very Accurate. Participants were asked to respond to each statement based on how accurately it describes them at that moment, rather than how he/she felt in the past or how another person may feel about him/her. This questionnaire took approximately 10 minutes to complete. The IPIP scales have average reliability coefficients ranging from .83-.94 in previous studies and an average criterion validity of .65 through regression analyses for the five subscale measures were established from the NEO-PI-R, the Temperament and Character Inventory, and the California Psychological Inventory (Goldberg, 1999).

Conners Adult ADHD Rating Scale

The CAARS is a self-response inventory based on the ADHD DSM-IV-TR Symptom subscales, and the Inconsistency index for ADHD (Conners, 2004). There are 66 items on the questionnaire, which assess the major characteristics of ADHD according to the DSM-IV-TR criteria. The subscales are impulsivity, hyperactivity, inattention, and problems with self-concept. The task took approximately 10 minutes to complete. Each self-report item is a statement intended to assess one of the ADHD characteristics, based on a person's self-assessment of their behavior (e.g. "I blurt out things."). Participants answered each item based on how accurately the statement describes them in terms of the frequency in which they engage in each behavior, using a 4-point rating scale ranging from "not at all, never" to "very much, very frequently", and in the context of the time in which he/she was tested. Reliability coefficients ranged from .74-.95, and validity was established, based on ADHD subtype from DSM-IV criteria (Christiansen et al., 2011). Significant correlations were found for all scales, ps<.001, and correlations between the CAARS, Barret Impulsiveness Scale (BIS), and the Wender Utah Rating Scale (WURS) were significant ps<.001, based on DSM-IV diagnostic criteria for ADHD.

Sternberg Working Memory Task

The working memory task was presented using Superlab software, and consisted of 132 trials. It was retrieved from Superlab's website (www.superlab.com) and replicates Sternberg's study (1966) on retrieval of information held in working memory. The first 12 trials were used as practice trials to allow the participant to become familiar with the task and computer equipment. Participants were instructed by both the researcher and by written instructions presented to the participant by the program. On each trial the participant was presented with a string of numbers presented one at a time. The participant was instructed to memorize the list of numbers. A cue signal was presented for two seconds after the final number in the memory set was presented. Following the cue signal a single number was presented on screen. The participant had to respond as to whether this number was part of the original set of number(s) originally presented. If the number was part of the set, the participant pressed “/” on the keyboard. If the number was not part of the set, the participant pressed “z” on the keyboard. The task took approximately 15 minutes to complete. The software recorded the reaction time, the size of the memory set, the response made, and whether the participant responded correctly.

Intermediate Visual and Auditory Continuous Performance Test

The IVA continuous performance test is a 20 minute go/no-go reaction time test, with the first 7 minutes consisting of practice trials. Practice trials allow the participant to understand the directions and to become familiar with the software’s presentation of stimuli. On each trial participants were presented with the number “1” or the number “2” either visually on the computer monitor or auditorily through a set of speakers. Participants were instructed to click the left mouse button whenever they see or hear “1” and to do nothing if they see or hear a “2”.There are five sets of two 50-trial blocks in this test. The first 50-trial block per set consisted of the target stimuli being presented approximately 80% of the time. The second 50-trial block of a set consisted of the target stimuli being presented approximately 20% of the time. This task is primarily a test of attention and response control, but also assessed individual levels of hyperactivity, both of which are commonly observed in ADHD. The program also measured reaction times, the number of incorrect clicks, and the number of times that the mouse is clicked prior to presentation of stimuli. On the basis of this information the IVA software provided a number of subscales assessing various aspects of attentional processes (Prudence, Consistency, Vigilance, Stamina, Focus, Speed, Balance, and Persistence). Separate scores for each aspect of performance were provided for both the visual and auditory modalities of stimulus presentation.

Prudence is a measure of impulsivity and response inhibition based on the number of button presses that occur outside of the designated response window. *Consistency* measures the participant's ability to stay on task and is determined by the pattern of sequential correct responses prior to an incorrect response or error. *Vigilance* is a measure of inattention based on the number of errors in the task. *Stamina* examines the reaction time differences from the beginning and end of the test. *Focus* reflects the total standard deviation of the speed of all correct responses. *Speed* consists of the reaction time of all correct responses. *Balance* examines whether the participant better processes information in a visual or an auditory modality. For example, if a person processes information better visually, the scores will show a slider bar lining up with Visual than Auditory due to the greater amount of correct responses visually. Lastly, *Persistence* was used to assess mental or motor fatigue and is determined by the pattern of reaction times and user error rates over time.

Procedures

Participants arrived at the Cognitive Psychophysiology Lab on the third floor of the psychology department at the appointed date and time, where they met the researcher. Upon arriving at the lab, they were greeted by the researcher and given an informed consent document to sign and return to the researcher. Once the participant gave consent to participate, he or she was given a demographics questionnaire to complete. Following the completion of the demographics questionnaire, the researcher administered the IPIP Big-Five Factor 50-item questionnaire and the CAARS.

Upon completing the CAARS, the participant was given a short 2 minute break. This allowed the researcher to load one of the two behavioral assessment tasks (i.e., Sternberg task and the IVA task) on the computer. The administration of the IVA task and the Sternberg task were counterbalanced to control for the confounding effects of fatigue and boredom. A 2 minute break was given between each behavioral task to allow the researcher to load the next task, as well as to reduce the effects of fatigue on the participant. Instructions were explained by the researcher prior to every questionnaire, inventory, and behavioral task, and any questions were answered at that time.

Following the completion of the final behavioral task, the participant was thanked and debriefed. Additional information about the research was provided to participants, including the expected pattern of results. Participants will be told that they could contact the investigator at a later time if they had any additional questions.

Data Reduction

Each participant's data from the demographics questionnaire, CAARS, and IPIP Big-Five Factor 50-item questionnaire scores were transferred from paper to SPSS, where it was combined with the data from the IVA performance test and Superlab test.

IPIP Big-Five Questionnaire: Each item within the IPIP Big-Five Factor questionnaire was coded based on the positive or negative wording of a statement, and corresponds to one of the five personality subscales. Positively worded items are scored on a 1-5 scale, with "very inaccurate" responses given a value of 1 and "very accurate" response are assigned a value of 5. For negatively worded items, the scores are reversed. The sum of the scores for each subscale of personality were calculated and entered into

SPSS. Higher scores for a subscale represent a greater chance of a person having those particular personality traits, such as agreeableness or extraversion.

Connors Adult ADHD Rating Scale (CAARS): Each of the 66 items from the CAARS contributes to one of the 4 subscales. Statements answered as “Not at all, Never” were scored with a 0 while statements answered as “Very much, very frequently” were scored with a 3. Negatively worded items were reversed scored. Subscale scores were created by summing the scores for items contributing to each subscale. Higher scores for a subscale represented a higher likelihood that an individual is characterized with that issue, such as inattention.

Intermediate Visual and Auditory Continuous Performance Task (IVA): The IVA task software provides a printout of each participant’s subscale scores. Individual items were analyzed on both raw scores, which reflect an objective score of their performance, as well as quotient scores that are based on a percentile to the participant’s cohort of similar age, gender, and personality range. The printout provides scales for both auditory and visual responses, indicating whether “hyperactive” responses were primarily due to visual or auditory stimuli being presented. The report also provided graphs of the range of the behavior scores, such as Prudence or Hyperactivity, which are also measured on a quotient score. The raw scores for each subscale were entered into SPSS.

Sternberg Task: Sternberg task data was analyzed by SPSS and Statistica software. Reaction times of less than 50 ms or more than 3 seconds were treated as missing values. The missing values were replaced by the average of the scores above and below them. The presence of more than 2 sequential missing data points resulted in the exclusion of the participant’s data from further analyses. The first 12 “practice” trials of working memory scores were not included in the spectral analyses. Lastly, because spectral analysis detects periodicities in responding that are unrelated to task performance, the means for each task condition were subtracted from the reaction times in those conditions to create a set of residuals. Once all scores were adjusted, the data was exported into Statistica.

Spectral Analysis on Reaction Time Residuals

Spectral analysis was performed on the time series of residuals derived from the Sternberg Task. Using Statistica software, a profile of performance was produced in terms of the degree of variability (Power) attributable to cycles of every possible length (i.e., the period of each cycle). Period was used instead of frequency because the value for the period of a cycle is in units of the number of trials needed to form a complete cycle - a more intuitively accessible unit than that of frequency. The periodogram of these scores was smoothed in order to reduce the influence of outliers. These smoothed periodogram values are referred to as values for *spectral density.* The resulting curve is plotted on a log (Power)- log (Period) spectral density plot because this log-log format produces an approximately linear relationship between the two log transformed variables. Separate data sets were exported into Statistica that contain the values for the log of power and the log of period. The slope of each participant's spectral density plot was obtained by predicting the log of power from the log of period.

For spectral analysis, the exponent of period (the inverse of frequency) is represented by the slope of the regression line. This exponent is what determines the "color" of the noise. If the slope resembles 1/f or "pink" noise as hypothesized, then it will be 1. This means that longer cycles accounted for more variability across time than shorter cycles. If cycles of all possible lengths accounts for approximately the same proportions of variability, the slope would be 0 and would resemble white noise.

Research Questions

A correlational analysis was conducted in SPSS examining the relationships among measures derived for spectral analyses of working memory data, the scores from the IPIP personality inventory, and the collection of ADHD scores between the Conners Adult ADHD Rating Scale and the IVA performance test. SPSS examined these relationships using the correlation between ADHD and cognitive functioning, between the slope of the regression line for the noise calculated and ADHD, and between the slope of the regression line for the noise and cognitive performance. Relationships were calculated using the correlations between the ADHD scores and personality scores, and between personality and cognitive performance scores. This determined if all relationships are present to examine if there is a multi-mediation effect.

For evidence of relationships for a multi-mediation effect, two mediation analyses were conducted using the Sobel Test to determine whether (a) power spectral density slopes and/or (b) any personality variables at least partially influenced the relationship between ADHD and cognitive performance on the IVA task. It uses the regression and standard error values of each behavioral, personality, and ADHD test (see Figure 8). Each Sobel Test includes ADHD as the independent variable and a measure of cognitive performance on the IVA task as the dependent variable. Personality and behavioral variability slopes would be tested as separate mediators.

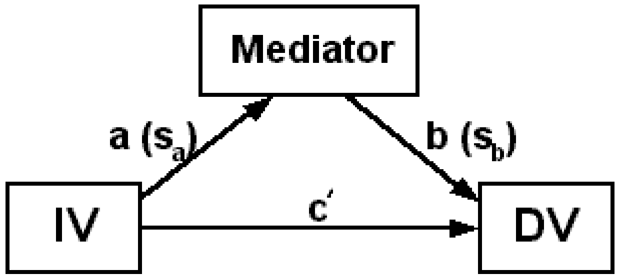

Figure 8. Mediation Model developed by Baron & Kenny (1986). In order for the mediation model to be tested, there must be significant relationship between all variables in the equation.

The Sobel test determines the mediator effect's size of influence and whether it is statistically different from zero (Baron & Kenny, 1986). The current relationship between the independent variable and dependent variable is listed as (c). Regression analyses provide the regression coefficients between the independent variable and mediator (a) as well as between the mediator and the dependent variable (b). It also provides the standard error values (in parenthesis). These numbers are entered into the Sobel test to calculate the critical ratio of a and b to determine the strength of the mediator's effects on the relationship between the independent variable and dependent variable (c'), and the significance level of the mediator's effects (p). If this p-value is statistically different from zero, then a partial mediation is observed. Only when the Sobel test produces a z-score that represents a complete change in relationship from ADHD scores and IVA performance as a result of the mediator's influence, c – c' = 0, would a full mediation be observed.

Lastly, hierarchical regression would be conducted in SPSS to test the relative predictive power of personality and power-spectrum slope variables in predicting IVA measures of cognitive function. This procedure works by calculating the influence of a mediator (A) between ADHD and performance, then adding the second mediator (B) to calculate its influence beyond the effects already accounted for by A. The regression is conducted twice to determine whether A or B has a greater individual influence beyond the other's influence.

Summary of Hypotheses and Statistical Analyses

1. Consistent with the model presented in Figure 7, significant correlations were predicted to be observed between ADHD measures obtained from the CAARS and measures of cognitive function obtained from the IVA task. These relationships comprised the "direct effect" presented in the model.
2. Significant correlations were hypothesized to be observed between CAARS measures and the slope of power spectral density plots describing the pattern of behavioral variability during performance of the Sternberg working memory task.
3. Significant correlations were predicted to be observed between the slope of power spectral density plots and IVA subscale scores.
4. Behavioral variability, as measured by the slope of power spectral density plots of reaction time data, was anticipated to serve as at least a partial mediator of the relationship between ADHD-related variables and cognitive performance.

   Because of the large number of correlations involved, a modified version of Baron and Kenny's (1986) method for testing for the presence of a mediation effect was needed. A path model of the effects present in a mediation model, with the symbols adopted by Baron and Kenny (1986), are presented in Figure 8. The average correlation coefficient between CAARS subscales and IVA measures was used as the value for path *c* (the direct effect). The average regression between

CAARS subscales and the slope of power spectral density plots were used as the value of path *a*. The average value for the standard error of *a* when CAARS subscales were used to predict the slope of power spectral density plots were used as the value for s_a. The average regression between the slope of power spectral density plots and IVA subscales was used as the value of path *b*. When controlling for ADHD scores, the average value for the standard error of *b* when the slope of power spectral density plots was used to predict IVA subscales was used as the value for s_b. Values for *c*, *a*, s_a, *b*, and s_b were used to calculate c-*c'*, the estimated change in strength of the relationship between CAARS subscales and IVA measures, controlling for the slope of power spectral density plots (behavioral variability) and tests for significance. The Sobel test was used to determine whether the value for *c'* is reduced significantly in size, compared to *c*.

5. Significant correlations were predicted to be observed between CAARS subscales and scores for the big five measures of personality.
6. Significant correlations were hypothesized to be observed between the big five measures of personality and IVA measures.
7. Personality variables were believed to serve as partial mediators of the relationship between ADHD-related variables and cognitive performance. The same modified version of Baron and Kenny's (1986) method for testing for the presence of a mediation effect was used to test this hypothesis as in hypothesis 4. The average correlation coefficient between CAARS subscales and IVA measures was used as the value for path *c* (the direct effect). The average regression between CAARS subscales and the measures of personality was used as the value

of path *a*. The average value for the standard error of *a* when CAARS subscales are used to predict personality measures was used as the value for s_a. The average regression between personality measures and IVA subscales was used as the value for path *b*. When controlling for ADHD scores, the average value for the standard error of *b* when personality measures are used to predict IVA subscales was used as the value for s_b. Values for *c*, *a*, s_a, *b*, and s_b were used to calculate c-*c'*, the estimated change in the strength of the relationship between CAARS subscales and IVA measures, controlling for personality measures, and tests for significance. The Sobel test was used to determine if the value for *c'* is reduced significantly in size, compared to *c*.

8. The unique contribution of behavioral variability in predicting IVA subscales was determined by adding measures of personality in a first block of variables predicting an IVA measure and then obtaining the change in the multiple squared correlation when the slope of power spectral density plots is added in a second block of predictors.
9. The unique contribution of personality measures in predicting IVA subscales was determined by adding the slope of power spectral density plots in a first block of variables predicting an IVA measure and then obtaining the change in the multiple squared correlation when personality measures are added in a second block of predictors.

CHAPTER 4: RESULTS

Comparing CAARS and IVA Scores

The mean Total score for the Connors Adult ADHD Rating Scale was 17.24 (*SD* = 9.41). The mean IVA Full Response score was 97.65 (*SD* = 16.57). Out of 192 possible combinations of CAARS and IVA variables, only six correlations were statistically significant. This means that there were fewer significant correlations between ADHD and attention-related variables than would be expected to occur due to chance. Table 1 provides the means, standard deviations, and reliability coefficients of the ADHD scores. Table 2 provides the means and standard deviations of the IVA scores. The Cronbach's alpha obtained from the data for the overall CAARS measure was .932.

Higher scores in Hyperactivity were associated with lower scores of Visual Readiness, $r(77) = -.23$, $p = .044$. Higher scores of DSM Inattentive Symptoms were associated with lower scores of Auditory Prudence, $r(77) = -.24$, $p = .023$, Auditory Focus, $r(77) = -.23$, $p = .039$, and higher instances of Hyperactive Events, $r(77) = .25$, $p = .029$. Lastly higher ADHD Total Symptoms were associated with lower scores of Auditory Focus, $r(77) = -.23$, $p = .039$ and higher instances of Hyperactive Events, $r(77) = .22$, $p = .049$. Table 3 displays correlations between CAARS and IVA measures.

Comparing CAARS and Personality Scores

Means, standard deviations, and reliability coefficients for each of the IPIP variables are provided in Table 4. When compared with CAARS scores, 15 out of 40 possible correlations were significant, with the majority involving Emotional Stability and Conscientiousness with these CAARS scores. Table 5 provides correlations between CAARS and IPIP variables.

Table 1

Descriptive Statistics of CAARS Scores

Variable	*M*	*SD*	α
Inattention_Memory Problems	11.12	7.12	.89
Hyperactivity_Restlessness	15.36	7.63	.89
Impulsivity	9.92	6.15	.86
Self Concept Problems	6.11	4.35	.87
DSM4_Inattentive Symptoms	8.82	5.68	.88
DSM4_Hyperactive Impulsive Symptoms	8.42	4.57	.77
DSM4_ADHD Symptoms Total	17.24	9.41	.90
ADHD Index	11.17	5.88	.81

Table 2

Descriptive Statistics of IVA Scores

Variable	*M*	*SD*
Full Response	97.65	16.57
Full Attention	96.22	22.41
Auditory Prudence	96.61	3.21
Visual Prudence	94.68	4.43
Auditory Consistency	76.81	6.26
Visual Consistency	77.10	5.06
Auditory Stamina	95.26	7.15
Visual Stamina	97.65	7.91
Auditory Vigilance	98.27	2.90
Visual Vigilance	98.24	3.94
Auditory Focus	76.17	5.59
Visual Focus	78.38	5.32
Auditory Speed	565.19	72.53
Visual Speed	431.82	50.68
Balance	76.59	7.16
Auditory Readiness	90.19	6.11
Visual Readiness	89.18	5.78
Auditory Comprehension	99.33	1.19
Visual Comprehension	99.01	3.06
Auditory Persistence	103.20	25.94
Visual Persistence	109.93	26.77
Auditory Sensory_Memory	285.19	84.83
Visual Sensory_Memory	244.37	29.01
Hyperactive Events	3.53	3.71

Table 3

Correlations between IVA and CAARS Variables

Variable	IMP	HR	I	SCP	D4IS	D4HIS	D4AST	AI
FR	-.17	-.03	-.11	.05	-.19	-.09	-.16	-.05
FA	-.02	.11	-.08	-.12	-.01	.03	.01	-.03
AUDP	-.18	-.18	-.07	.15	-.24*	-.16	-.22	-.06
VISP	-.14	-.08	-.09	.01	-.21	-.13	-.19	-.08
AUDC	-.16	-.14	-.14	.08	-.22	-.16	-.21	-.08
VISC	-.05	-.09	-.03	.04	-.11	-.06	-.10	-.05
AUDS	-.12	.20	-.04	.03	-.07	.12	.01	.01
VISS	-.14	.08	-.01	.04	-.07	.00	-.04	.02
AUDV	-.11	-.00	-.06	-.07	-.12	-.02	-.09	-.05
VISV	.01	.03	-.01	.01	-.02	-.05	-.04	-.05
AUDF	-.12	-.18	-.17	.03	-.23*	-.19	-.23*	-.13
VISF	.09	.08	-.05	.04	.05	-.04	.01	.06
AUDSP	-.09	-.17	.07	.06	-.07	-.10	-.09	-.05
VISSP	-.12	-.13	.03	.00	-.10	-.11	-.11	-.06
B	.03	.08	-.05	-.05	.00	.00	.00	.01
AUDR	-.16	-.15	-.13	-.04	-.18	-.12	-.17	-.15
VISR	-.14	-.23*	.02	.03	-.20	-.19	-.21	-.10
AUDCO	-.11	.00	-.16	-.01	-.14	-.06	-.11	-.05
VISCO	-.02	.00	-.14	-.01	-.11	-.08	-.10	-.09
AUDPE	.20	.19	.10	.15	.20	.09	.17	.19
VISPE	.03	.06	-.07	-.00	.04	-.09	-.02	.05
AUDSM	-.16	-.05	.05	.00	-.13	-.08	-.12	-.07
VISSM	-.14	.00	-.01	.07	-.15	-.03	-.10	-.07
HE	.21	.12	.02	-.03	.25*	.15	.22*	.14

Note. **p*<.05; IMP = Inattention_Memory Problems; HR= Hyperactivity_Restlessness; I = Impulsivity; D4IS = DSM4 Inattentive Symptoms; D4HIS= DSM4Hyperactive_Impulsive Symptoms; D4AST= DSM4 ADHD Symptoms Total; AI = ADHD Index; FR = Full Response; FA = Full Attention; AUDP = Auditory Prudence;VISP= Visual Prudence; AUDC = Auditory Consistency; VISC = Visual Consistency; AUDS= Auditory Stamina; VISS= Visual Stamina; AUDV= Auditory Vigilance; VISV= Visual Vigilance; AUDF= Auditory Focus; VISF = Visual Focus; AUDSP = Auditory Speed; VISSP= Visual Speed; B = Balance; AUDR = Auditory Readiness; VISR = Visual Readiness; AUDCO = Auditory Comprehension; VISCO = Visual Comprehension; AUDPE =Auditory Persistence; VISPE = Visual Persistence; AUDSM = Auditory Sensory_Motor; VISSM= Visual Sensory_Motor; HE = Hyperactive Events.

Table 4

Descriptive Statistics of IPIP Scores

Variable	*M*	*SD*	α
Extraversion	33.77	7.69	.884
Agreeableness	41.11	4.90	.734
Conscientiousness	36.39	6.58	.823
Emotional Stability	30.66	6.76	.831
Intellect_Imagination	35.51	5.44	.779

Table 5

Correlations between CAARS and IPIP Variables

Variable	E	A	C	ES	II
IMP	-.23*	-.02	-.63**	-.30**	-.11
HR	.20	.16	-.23*	-.12	.12
I	.06	-.19	-.18	-.55**	-.06
SCP	-.35**	.08	-.13	-.62**	-.03
D4IS	-.18	-.05	-.57**	-.26*	-.13
D4HIS	.13	.08	-.27*	-.24*	.08
D4AST	-.05	.01	-.48**	-.27*	.08
AI	-.16	.00	-.26*	-.50*	-.01

Note. *p <.05; **p<.01; *E* = Extraversion; A = Agreeableness; C = Conscientiousness; ES = Emotional Stability; II = Intellect Imagination; IMP = Inattention_Memory Problems; HR = Hyperactivity_Restlessness; I = Impulsivity; SCP = Self Concept Problems; D4IS = DSM4 Inattentive Symptoms; D4HIS = DSM4 Hyperactive/Impusive Symptoms; D4AST = DSM4 ADHD Symptoms Total; AI = ADHD Index.

Comparing Personality and IVA Scores

Out of 120 possible combinations of correlations between personality and IVA attention variables, only five were significant. This indicates that the number of significant relationships occurring among these variables is less than what would be expected by chance alone. Higher scores of Conscientiousness resulted in higher scores of Auditory Prudence, $r(77) = .24$, $p = .037$, and Visual Prudence, $r(77) = .26$, $p = .023$. Higher scores of Emotional Stability were asscociated with lower scores of Visual Readiness, $r(77)= -.23$, $p = .046$. Lastly, higher scores of Intellect/Imagination were associated with higher scores of Full Response Control, $r(77) = .23$, $p = .041$, and Visual Persistence, $r(77) = .24$, $p = .032$. Table 6 provides the correlations among these task variables.

Comparing CAARS and Spectral Density Slopes

The mean spectral density slope value for the entire sample was .33 ($SD = .44$). This slope was significantly different from zero, $t(78) = 6.66$, $p <.001$. The dominant period for this slope was 23.22 seconds ($SD = 36.64$). See Figure 9 for the distribution of all spectral density slopes found within the Sternberg Working Memory task residuals. There is a small, yet significant, pattern in the way that the power is distributed across periods, rather than the variability being distributed across all periods equally. When comparing the mean slope value with CAARS scores, none of the eight possible correlations were significant. Table 7 lists all of the correlation coefficients.

Table 6

Correlations between IVA and IPIP Variables

Variable	E	A	C	ES	II
FR	.00	.12	.19	-.01	.23*
FA	.04	.09	-.07	.19	-.09
AUDP	-.09	-.03	.24*	-.19	.05
VISP	.02	.11	.26*	-.07	.21
AUDC	-.07	-.00	.05	.01	.18
VISC	-.13	.04	.03	.03	.06
AUDS	.06	.08	.07	.03	-.04
VISS	.06	.14	.15	-.02	.15
AUDV	-.07	.05	.10	.07	-.11
VISV	-.00	.09	-.11	.12	-.11
AUDF	-.06	.01	.04	.11	.07
VISF	-.01	.01	-.06	.12	.11
AUDSP	.07	-.03	.12	-.12	.02
VISSP	.04	-.03	.15	-.09	.07
B	-.10	.03	-.03	.05	.00
AUDR	.02	-.00	-.00	.01	.20
VISR	.04	-.26	.05	-.23*	.05
AUDCO	-.08	.18	.07	.15	.01
VISCO	.01	.17	-.06	.11	.01
AUDPE	.02	-.00	-.20	-.12	-.14
VISPE	.11	.17	.07	.22	.24*
AUDSM	.08	.04	.12	-.10	-.03
VISSM	.03	.13	.14	-.15	.11
HE	-.14	-.09	-.17	-.04	-.11

Note. **p*<.05; E = Extraversion; A = Agreeableness; C = Conscientiousness; ES = Emotional Stability; II = Intellect_Imagination;FR = Full Response; FA = Full Attention; AUDP = Auditory Prudence; VISP = Visual Prudence; AUDC = Auditory Consistency; VISC = Visual Consistency; AUDS = Auditory Stamina; VISS = Visual Stamina; AUDV= Auditory Vigilance; VISV= Visual Vigilance; AUDF = Auditory Focus; VISF = Visual Focus; AUDSP = Auditory Speed; VISSP = Visual Speed; B = Balance; AUDR = Auditory Readiness; VISR = Visual Readiness; AUDCO = Auditory Comprehension; VISCO= Visual Comprehension; AUDPE = Auditory Persistence; VISPE = Visual Persistence; AUDSM = Auditory Sensory_Motor; VISSM = Visual Sensory_Motor; HE = Hyperactive Events.

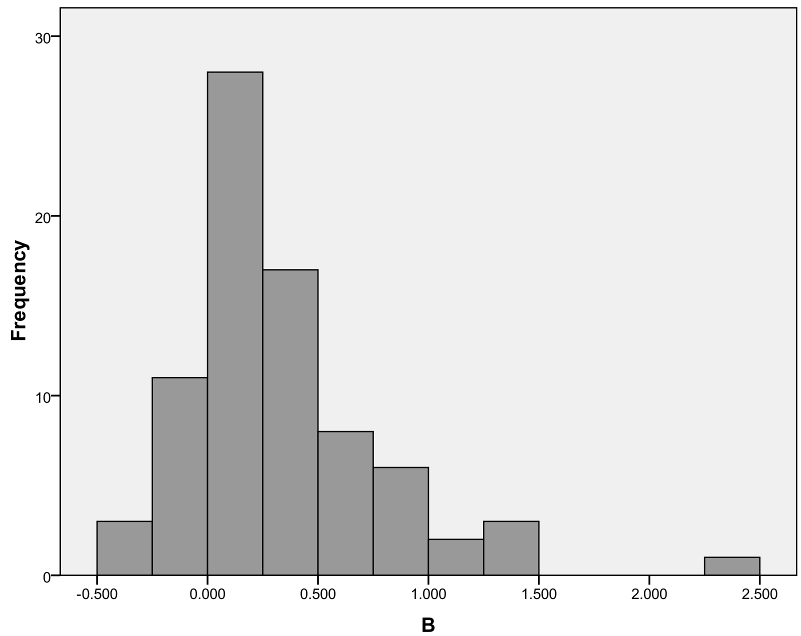

Figure 9. Histogram of Spectral Density Values. This represents the distribution of variability found within the Sternberg Working Memory Task residuals.

Table 7

Correlations between Spectral Density Slope and CAARS Variables

Variable	Slope
Inattention_Memory Problems	.04
Hyperactivity_Restlessness	-.07
Impulsivity	.14
Self_Concept Problems	-.06
DSM4_Inattentive Symptoms	.03
DSM4_Hyperactive Impulsive Symptoms	-.02
DSM4_ADHD Symptoms Total	.01
ADHD Index	.09

Comparing IVA scores and Spectral Density Slopes

Out of the 24 possible correlations between spectral density slope and IVA variables, none were significant. This suggests that no relationship exists between attentional performance and the profile of cycles in reaction times obtained during performance of a working memory task. Table 8 shows the correlation coefficients between the spectral density slope measure and IVA variables.

Table 8

Correlations between Spectral Density Slope and IVA Variables

Variable	Slope
Full Response	-.06
Full Attention	.02
Auditory Prudence	.12
Visual Prudence	-.06
Auditory Consistency	.13
Visual Consistency	.06
Auditory Stamina	-.21
Visual Stamina	-.05
Auditory Vigilance	.09
Visual Vigilance	.07
Auditory Focus	.07
Visual Focus	.06
Auditory Speed	-.16
Visual Speed	-.16
Balance	.01
Auditory Readiness	-.11
Visual Readiness	-.07
Auditory Comprehension	.16
Visual Comprehension	.12
Auditory Persistence	.16
Visual Persistence	.13
Auditory Sensory_Motor	-.12
Visual Sensory_Motor	.05
Hyperactive Events	-.06

Comparing Personality Scores with Spectral Density Slopes

No personality variable was correlated significantly with spectral density slope values. Table 9 provides the correlations among these variables. This indicates that personality does not predict the cycles of performance of reaction times during performance of a working memory task.

Table 9

Correlations between Spectral Density Slope and IPIP Variables

Variable	Slope
Extraversion	.06
Agreeableness	.08
Conscientiousness	.05
Emotional Stability	-.01
Intellect_Imagination	.19

CHAPTER 5: DISCUSSION

The purpose of this study was to determine whether (a) the spectral density of performance over time and (b) personality variables at least partially mediate relationships between ADHD status and measures of cognitive performance. It was hypothesized that statistically significant relationships would exist between our primary variables in the mediation model, ADHD and cognitive performance. It was also hypothesized that both variables, personality and spectral density of performance, would serve as partial mediators between CAARS and IVA variables.

The study findings were unable to meet the criteria of a multi-mediation study. There were not enough significant relationships among our primary variables to constitute a possible mediation of a relationship between CAARS and IVA variables by either spectral density slope values or personality variables. Several secondary significant relationships were found in this study, such as between *Extraversion* and *Inattention_Memory Problems*, but ultimately the main prediction of a relationship between ADHD and cognitive performance was not supported.

ADHD and Cognitive Processing

The most interesting finding was the lack of a relationship between the two sets of variables needed to set the foundation for our hypothetical model. Out of 192 possible combinations of variables between ADHD and cognitive functioning, only six were significant. Even compared to situations based on chance this study produced fewer significant relationships. Unlike studies which have shown significant and strong correlations between these two sets of variables (e.g., Castellanos et al., 2006; Roth & Saykin, 2004), our results raise the possibility that the two are unrelated. Any behaviors observed in individuals with ADHD that are thought to be influenced by the disorder would have no cognitive foundation.

Because ADHD is thought to have significant relationships with many factors, it is likely that another variable plays a much larger role in its relationship with cognition. For our study, the presence of another factor could possibly have mitigated the chances of finding cognitive deficits in our participants. For example, no significant group differences were found between ADHD and non-ADHD participants on their IVA cognitive performance scores. However, many of the participants were noted as being on medication at the time of testing, an effect which could temporarily reduce or eliminate any symptoms associated with the disorder at the time of testing. In addition, the range of ADHD scores was restricted to primarily higher functioning individuals in the sample, so the results are likely to differ significantly from other samples.

Personality is another variable which is thought to play a significant role in both ADHD-related behaviors and cognitive processing. For this study, the most significant findings between the Five-Factor IPIP test and CAARS scale results were negative relationships for Emotional Stability and Conscientiousness with ADHD and IVA variables. This means that, in theory, the more conscientious and emotionally stable a person is, the less likely that he/she is going to display symptoms of ADHD. In addition, both Visual Prudence and Auditory Prudence scores were significantly correlated with Conscientiousness. This is interesting because Prudence refers to non-impulsivity, so the results would suggest that the more conscientious a person is, the more likely he/she is to provide higher scores of Prudence. This means that an individual with high prudence should be able to consciously hold back the urge to respond. A person with ADHD would therefore be less conscientious of his/her actions and would be more likely to respond impulsively.

Spectral Density Slopes as a Function of Behavior

Spectral analysis provided a simple way of quantifying the frequencies present in the complex wave of residual data for the Sternberg Working Memory task. The slope of the line calculated represents the change in the variability, or power, associated with each change in frequency in the original waveform. This slope is signified as the “color” of the noise found in the behavior.

The results suggest a presence of “light pink noise” found in tasks of working memory. The result of individual behavior that is not task-related is not random, but rather provides a systematic pattern of variability. This is consistent with previous research on time estimation, mental rotation, and reaction time tasks, conducted both on ADHD and non-ADHD participants (Frum & Pierce, 2011; Gilden et al., 1995; Gilden 2001; Gilden & Hancock, 2007). However, this study was unable to find “pink” noise in the same fashion found in the other tasks (i.e., a slope approximately equal to 1.0). For example, Gilden and Hancock (2007) acquired spectral density slopes of approximately 1 for participants with ADHD, using tasks of mental rotation.

The study was unable to locate any significant relationships between spectral density slopes of behavior and any other variable in our proposed model. The findings suggest that the pattern of variability in a behavior may not play a significant role in influencing the relationship between ADHD and cognitive performance. However, a sample that is limited to higher functioning individuals would differ in determining whether the relationship exists, compared to another sample. It also suggests that it is not significantly related to personality. Because our spectral analysis focused on the residuals of the working memory test, the "error" scores thought to be unrelated to the test itself, it is possible that the systematic pattern displayed in the data is the result of another internal process that was not being measured, such as motivation.

Strengths, Limitations, and Future Research

The study provides additional knowledge about ADHD, and how there may not necessarily be a relationship with cognition as previously thought. It also adds further evidence of a relationship between ADHD and personality. Emotional Stability and Conscientiousness were most strongly associated with CAARS and IVA scores, so it is possible that the behaviors observed within the disorder are more emotionally based than intellectually based. This means that an individual with ADHD is more likely to use emotion to drive their behavior than logic, perhaps to a greater degree than expected in the normal person.

This study also provides additional support that behavioral variability is not random. While it may be unclear as to what causes specific patterns or why "error variance" is not a purely random phenomenon, it is becoming clear that factors exist, which affect both controlled and uncontrolled responses. Though a cure has yet to be discovered for ADHD, it appears that additional methods could be employed to identify specific symptoms based on time-series analysis.

One limitation to the results is due to the sample. While the number of participants recruited helped to provide a hypothesized significant finding for a power greater than .80 for spectral analysis, it may require even more participants to discover significant mediation effects. However, it is also possible that the effects are smaller than we predicted. Furthermore, the results from one specific undergraduate sample may not be generalizable to other populations. The sample recruited for this study was limited to mostly higher functioning individuals, so scores of ADHD may appear lower than those found in other samples.

In addition, spectral analysis focuses on behavior across time, which means that fatigue would become a significant confound if the study were too long. Although breaks were provided, this may not have been sufficient, based on the number of tasks administered. Such fatigue may increase or decrease the possibility of seeing ADHD-related behaviors in reaction time tasks and tasks of working memory. Once a person's physical and cognitive resources have become depleted, the individual may only be able to use their basic or unconscious cognitive processes in providing responses. Studies of self-regulation would suggest that even individuals without ADHD may exhibit increased error rates and more impulsive responses that would be similar to ADHD once they experience lower levels of self-control (Berger, 2011; Muraven, Tice, & Baumeister, 1999). Additional research combining self-regulation and time-series analyses would be necessary to evaluate these theories.

Ultimately, spectral analysis has provided an additional method for looking at ADHD, and may be useful in predicting which individuals are likely to have the disorder. In time, this may be applicable to other disorders or illnesses which reflect changes in behavior across time. Discovering specific ranges of spectral density slopes in behavior may be able to improve classification of individuals in terms of mild, moderate, or severe cases of ADHD. It is an opportunity to broaden clinical psychology's theoretical and methodological horizons.

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Appendix A
Demographics Questionnaire

1. I am a:
   Male ________
   Female ___________

2. I am a:
   Freshman _________
   Sophomore __________
   Junior _________
   Senior _________

3. My age is : **___________**

4. What is your race (Check all that apply)?
   Caucasian _____
   African American _____
   Hispanic _____
   Asian- American ______
   Native American ______
   Other (please state) _________________________________

5. I am:
   Left-handed _______
   Right – handed ______

6. How much caffeine do you consume daily?
   None _______
   1 Soda/ Coffee/ Tea ________
   2-3 Sodas/ Coffee/ Tea ________
   4-5 Sodas / Coffee / Tea __________
   6+ Sodas / Coffee / Tea _________

7. How much caffeine have you consumed today?
   None _______
   1 Soda/ Coffee/ Tea ________
   2-3 Sodas/ Coffee/ Tea ________
   4-5 Sodas / Coffee / Tea __________
   6+ Sodas / Coffee / Tea _________

8. Are you currently on a sports team?
   Yes __________
   No ___________

9. How many hours of sleep do you get daily? ______________

10. How many hours of sleep did you get last night? __________

11. Please list any medication that you are currently taking below.

12. Have you ever been diagnosed with ADHD?
    Yes_________
    No__________ (if no, skip questions 13-15)

13. Are you currently diagnosed with ADHD?
    Yes __________
    No ___________

14. Have you ever taken medication for ADHD?
    Yes __________
    No ___________

15. Please list any medication that you have taken for ADHD.

Appendix B

IPIP Big-Five Factor 50-item Questionnaire

Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age. So that you can describe yourself in an honest manner, your responses will be kept in absolute confidence. Indicate for each statement whether it is 1. Very Inaccurate, 2. Moderately Inaccurate, 3. Neither Accurate Nor Inaccurate, 4. Moderately Accurate, or 5. Very Accurate as a description of you.

	Very Inaccurate	Moderately Inaccurate	Neither Accurate Nor Inaccurate	Moderately Accurate	Very Accurate	
1. Am the life of the party.	O	O	O	O	O	(1+)
2. Feel little concern for others.	O	O	O	O	O	(2-)
3. Am always prepared.	O	O	O	O	O	(3+)
4. Get stressed out easily.	O	O	O	O	O	(4-)
5. Have a rich vocabulary.	O	O	O	O	O	(5+)
6. Don't talk a lot.	O	O	O	O	O	(1-)
7. Am interested in people.	O	O	O	O	O	(2+)
8. Leave my belongings around.	O	O	O	O	O	(3-)
9. Am relaxed most of the time.	O	O	O	O	O	(4+)
10. Have difficulty understanding abstract ideas.	O	O	O	O	O	(5-)
11. Feel comfortable around people.	O	O	O	O	O	(1+)
12. Insult people.	O	O	O	O	O	(2-)
13. Pay attention to details.	O	O	O	O	O	(3+)
14. Worry about things.	O	O	O	O	O	(4-)
15. Have a vivid imagination.	O	O	O	O	O	(5+)
16. Keep in the background.	O	O	O	O	O	(1-)
17. Sympathize with others' feelings.	O	O	O	O	O	(2+)
18. Make a mess of things.	O	O	O	O	O	(3-)
19. Seldom feel blue.	O	O	O	O	O	(4+)
20. Am not interested in abstract ideas.	O	O	O	O	O	(5-)

21. Start conversations.	O	O	O	O	O	**(1+)**
22. Am not interested in other people's problems.	O	O	O	O	O	**(2-)**
23. Get chores done right away.	O	O	O	O	O	**(3+)**
24. Am easily disturbed.	O	O	O	O	O	**(4-)**
25. Have excellent ideas.	O	O	O	O	O	**(5+)**
26. Have little to say.	O	O	O	O	O	**(1-)**
27. Have a soft heart.	O	O	O	O	O	**(2+)**
28. Often forget to put things back in their proper place.	O	O	O	O	O	**(3-)**
29. Get upset easily.	O	O	O	O	O	**(4-)**
30. Do not have a good imagination.	O	O	O	O	O	**(5-)**
31. Talk to a lot of different people at parties.	O	O	O	O	O	**(1+)**
32. Am not really interested in others.	O	O	O	O	O	**(2-)**
33. Like order.	O	O	O	O	O	**(3+)**
34. Change my mood a lot.	O	O	O	O	O	**(4-)**
35. Am quick to understand things.	O	O	O	O	O	**(5+)**
36. Don't like to draw attention to myself.	O	O	O	O	O	**(1-)**
37. Take time out for others.	O	O	O	O	O	**(2+)**
38. Shirk my duties.	O	O	O	O	O	**(3-)**
39. Have frequent mood swings.	O	O	O	O	O	**(4-)**
40. Use difficult words.	O	O	O	O	O	**(5+)**
41. Don't mind being the center of attention.	O	O	O	O	O	**(1+)**
42. Feel others' emotions.	O	O	O	O	O	**(2+)**
43. Follow a schedule.	O	O	O	O	O	**(3+)**
44. Get irritated easily.	O	O	O	O	O	**(4-)**
45. Spend time reflecting on things.	O	O	O	O	O	**(5+)**
46. Am quiet around strangers.	O	O	O	O	O	**(1-)**
47. Make people feel at ease.	O	O	O	O	O	**(2+)**
48. Am exacting in my work.	O	O	O	O	O	**(3+)**
49. Often feel blue.	O	O	O	O	O	**(4-)**
50. Am full of ideas.	O	O	O	O	O	**(5+)**