EYE MOVEMENT, VISUAL ATTENTION, AND ADHD TRAITS

by

Zachary McKinley Saint

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Approved by:

____
William Canu, Ph.D., Thesis Director

____
Alan Arnholt, Ph.D., Second Reader

____
Andrew Smith, Ph.D., Departmental Honors Director

____
Jefford Vahlbusch, Ph.D., Dean, The Honors College

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Abstract

Current research on visual attention differences in college students with ADHD is limited. It is not yet known whether ADHD-related visual attention differences are due to deficits in visual *processing* or in visual *attention*. The current study uses the continuous performance task (CPT), along with eye-tracking technology, to test whether college students with higher self-reported ADHD symptoms spend less time looking at the designated target and glance away from the target more than those with lower ADHD symptoms. Those with a broader range of ADHD-related impairment showed deficits in visual attention. Interestingly, however, higher levels of ADHD symptoms predicted *better* performance on the visual attention task.

Eye Movement, Visual Attention, and ADHD Traits

Attention-deficit/hyperactivity disorder (ADHD) is a developmental disorder marked by symptoms of inattention, hyperactivity, and impulsivity, as well as deficits in executive functioning (American Psychiatric Association, 2013). Individuals with ADHD experience functional impairments in regards to academic achievement (de Zeeuw, van Beijsterveldt, Ehli, de Geus, & Boomsma, 2017), professional success (Nadeau, 2005), family life (Eakin et al., 2004; Murray & Johnson, 2006), social relationships (Gardner & Gerdes, 2015), and romantic relationships (Bruner, Kuryluk, & Whitton, 2015). ADHD is more common in children, with prevalence rates of around 9% (Visser et al., 2014); however, ADHD often continues into adulthood, with approximately 4.4% of adults in the United States being diagnosed with ADHD (Kessler et al., 2006).

While ample research is available on ADHD in children, far less research exists in regards to adults with ADHD. College students with ADHD, specifically, are an understudied population, even though 2 to 8% of college students report having ADHD. College students with ADHD have lower grade point averages and are less likely to graduate college than college students without ADHD (DuPaul, Weyandt, O'Dell, & Varejao, 2009).

Attention

Attention - in both those with and without ADHD - is the process of selectively concentrating on certain parts of the environment while ignoring other parts. According to Atkinson and Shiffrin's (1968) Stage Model of memory, attention acts as a filter to determine which sensory information from the environment is processed in working memory (WM) and eventually consolidated into long-term memory (LTM). All "knowledge" is thought to be stored in LTM. Without attending to a sensory stimulus in the environment (e.g., a class lecture), the chances of that information being encoded into personal knowledge are greatly reduced. Therefore, it is worthwhile to study the mechanisms by which people attend to and process information.

Attention can be divided into several components. Sustained attention (also known as "vigilance" or "alertness") is the ability to maintain attention on a target over a long period of time. Selective attention is the ability to resist impulses to attend to distracting stimuli; impaired selective attention translates to an increased vulnerability to distraction. Divided attention is the ability to divide the attention between more than one event or stimulus at a time (e.g., listening to a lecture while taking notes). As should be clear given the nature of the disorder, those with ADHD very often have distinct difficulties maintaining attention and ignoring distracting stimuli. These difficulties are not a problem of knowing where they *should* direct attention, but rather a problem of response inhibition; they are unable to inhibit responses toward a distracting stimulus (Barkley, 2015). Those with ADHD do not *perceive* distractions differently from others; they *respond* to distractors differently.

A study of adolescents found that moderate background noise may increase visual attentional performance in those with ADHD (Batho, 2014). These findings provide support for the moderate brain arousal (MBA) model, which states that those with ADHD function best with moderate environmental stimulation: not too much, not too little (Söderlund, Sikström, & Smart, 2007). The MBA model may also apply to visual stimulation: moderate visual stimulation in the environment may lead to increased visual attention in those with ADHD.

While those with ADHD show high distractibility, certain types of stimuli can be more distracting than others. In a study of auditory distractions, adults with ADHD showed deficits in selective attention; in other words, they were more distracted by irrelevant sounds than were non-ADHD controls during a serial recall task (Pelletier et al., 2016). In addition, both the ADHD and control groups were more distracted by sounds with more acoustic variability (i.e., sounds that were not consistent over time). Perhaps these findings may apply to visual distractions as well; those with ADHD may be more resilient to distractions that are static and consistent over time. However, to date, this possibility has not been empirically tested.

ADHD, Visual Attention, and CPT Performance

The test of visual attention used in the current study is called the continuous performance test (CPT), and has been used in studies of children and adults to measure traits of inattention. Using a version of the CPT, one study found that children with ADHD show significant deficits in overall visual attention, but not in sustained visual attention, compared to controls (Moreno-García et al., 2015). Meta-analyses of studies of adults with ADHD have found consistent attention deficits with moderate effect sizes as measured by CPT tests across studies (Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005; Hervey, Epstein, & Curry, 2004). Few studies have examined the performance of young adults or college students on CPT tests. The few studies that have been conducted on this population only found deficits in certain measures of visual attention. One study found significant differences between ADHD and control groups in omission errors (i.e., failing to respond to targets), but no significant differences in reaction times (RTs) or variability in RTs, two dependent variables frequently used to measure inattention on CPT tests (Weyandt et al., 2013). Another study found significant differences in RT variability, but not in RTs or omission errors (Advokat, Martino, Hill, & Gouvier, 2007). More research is necessary to determine specifically which aspects of visual attention and related visual behaviors are impaired in young adults with ADHD.

Eye Tracking

Eye-tracking technology is a method used by researchers to measure visual attention and eye movements. Data gathered from this technology gives researchers insight into the neurological basis of visual attention and visual processing. Eye movement can provide a lens through which to observe one's thought processes. It has been used to study attentional processes associated with many psychological disorders, including schizophrenia (Levy, Holzman, Matthysse, & Mendell, 1993), autism spectrum disorder (Sabatos-DeVito, Schipul, Bulluck, Belger, & Baranek, 2016), and major depression (Winograd-Gurvich, Georgiou-Karistianis, Fitzgerald, Millist, & White, 2006; for a review of the use of eye-tracking to study psychiatric disorders, see Bittencourt et al., 2013).

Traditional methods of measuring visual attention involve testing participants' performance on tasks that require the participant to visually attend to a target stimulus. This method, however, may be testing visual *processing* rather than visual *attention*. If participants are paying visual attention (i.e., looking at the stimulus) but not processing the information, their results on traditional attention tests like the CPT would incorrectly suggest that they are not paying attention. Traditional "performance test" measures of visual attention tell us the *what*, but not the *how*, of visual attention. Eye-tracking technology solves this problem by measuring visual attention directly at its source: the eye. The eye-tracking paradigm allows scientists to study not just whether or not an individual is paying attention, but also qualitative differences in *how* different populations of interest direct their attention. For example, why do those with ADHD have difficulties paying attention? Is it because they have trouble inhibiting glances toward distractors? Is it because of difficulties refocusing their attention after becoming distracted? Or is it that they have no problem keeping their eyes fixed on a target, but rather have deficits in processing ability? Eye-tracking studies aid in answering such questions by allowing researchers to examine specific characteristics of visual attention.

The eye movements that are commonly measured in eye-tracking experiments can be divided into two categories: saccades and fixations (Feng, 2011). A saccade is a quick eye movement from one focal point to another. In between saccades are fixations, periods of time in which the eye is stationary. Fixations allow the eye to capture a snapshot of the current visual field. Saccades can be divided into several types. Prosaccades (or visually-guided saccades; VGS) are saccades toward the target stimulus, while antisaccades (AS) are saccades away from the target. Memory-guided saccades (MGS) are saccades toward a remembered point. Additionally, smooth pursuit eye movements (SPEM), not considered saccades, are smooth eye movements that follow a moving stimulus.

Data gathered from eye-tracking technology can shed light on ADHD-related executive function deficits such as selective attention, sustained attention, and response inhibition. For instance, saccade latency (i.e., response time) is the time between the appearance of the target stimulus and the initiation of the saccade. Longer saccade latencies indicate deficits in attention (Rommelse, Van der Stigchel, & Sergeant, 2008) and thereby represent a potential dependent variable in studies of ADHD groups.

Eye Tracking and ADHD

Children and adolescents with ADHD. Eye-tracking studies of children and adolescents with ADHD have demonstrated disorder-related deficits in attention, response inhibition, and distractibility. In existent research, children with ADHD show consistent ADHD-related attention deficits. While reading, children with ADHD tend to make more vertical saccades than non-ADHD controls, indicating intermittent losses of focus while reading (Deans et al., 2010). Two other measures of inattention are response time and response variability. Children and adolescents with ADHD consistently show higher saccade latencies (i.e., slower response times) than non-ADHD controls. Higher saccade latencies have been documented across multiple eye-movement tasks (Rommelse et al., 2008; Van der Stigchel et al., 2007; Goto et al., 2010 - only in younger children). Studies also show consistently higher response variabilities than non-ADHD controls, indicating frequent lapses in attention (Rommelse et al., 2008).

Eye-tracking studies of children with ADHD show marked deficits in measures of response inhibition. They tend to make more anticipatory errors than controls on MGS tasks (Goto et al., 2010) and more errors on AS tasks (Goto et al., 2010; Rommelse et al., 2008), both of which indicate deficits in response inhibition. Older children with ADHD show less severe deficits related to response inhibition than do younger children (Goto et al., 2010). This suggests that the severity of some ADHD-related eye-movement differences, and associated underlying impairments, may lessen with age. Regardless, the extent to which these particular deficits persist into young adulthood is still unknown.

Children with ADHD have also been found to be more vulnerable to distractions than controls during vigilance tasks (Adams et al., 2009). However, one study of an oculomotor capture task found that ADHD boys were no more distracted than controls by a distractor stimulus, a finding that is inconsistent with the literature on ADHD-related response inhibition deficits (Van der Stigchel et al., 2007) and renders findings regarding measured oculomotor distraction inconclusive, to date.

One measure of distractibility that shows deficits in ADHD children is an increased number and duration of glances away from the target during a visual attention task. This pronounced tendency to intermittently glance away from the target stimulus has been shown in children with ADHD on vigilance/basic attention tests (Börger & van der Meere, 2000) and oculomotor capture tasks (Van der Stigchel et al., 2007), and has been shown in teens with ADHD on simulated driving tasks (Kingery et al., 2015). An important distinction of these findings is that in addition to being distracted by significant non-target stimuli, those with ADHD actually glance away (i.e., become distracted) towards nothing in particular in the absence of significant distractors. These findings support the present study's hypothesis that participants with ADHD will show longer and more frequent glances away from the target, even in the absence of "manipulated" distractors.

Adults with ADHD. While the literature in this area is sparse, past eye-tracking research of adults with ADHD suggests deficits in response inhibition and attention. More specifically, adults with ADHD show deficits in eye-movement measures related to response inhibition. Young adults have been shown to make more anticipatory saccades on MGS tasks, indicating an inability to inhibit or delay impulsive eye movements towards a stimulus (Ross et al., 2010). Furthermore, a study of people with ADHD from age 6 to 59 found that both younger and older adults with ADHD tend to make more errors on antisaccade tasks and more intrusive saccades on prolonged fixation tasks which require the participant to maintain their gaze on a stationary target (Munoz et al., 2003). Both of these findings suggest that adults with ADHD have difficulties regulating intrusive eye movements that do not contribute to the task at hand. While this study found that response inhibition ability improved from childhood to adulthood in both ADHD and control groups, those with ADHD never reached the normal range.

Munoz and colleagues (2003) also found deficits in attention related to ADHD. Both younger and older adults had longer response times (i.e., saccade latencies) and more response variability in prosaccade and antisaccade tasks than did non-ADHD controls. In contrast to the findings on response inhibition, these attention deficits persisted from childhood to adulthood. These findings suggest that whereas response inhibition deficits tend to improve by young adulthood, many young adults with ADHD likely still experience marked attention deficits that stay relatively constant throughout their lives.

Limitations of Past Research

As noted above, there have not been many eye-tracking studies of young adults or college students with ADHD, to date. The documentation of ADHD-related visual attention deficits in young adults has mostly relied upon patient reports of inattention, and associated functional impairments. Current research shows that symptoms of inattention persist into adulthood, whereas hyperactivity-impulsivity symptoms tend to improve by adulthood (Martel, von Eye, & Nigg, 2012). However, there is an absence of research of ADHD-related deficits in the neurological pathways of visual attention. Without this research, it is difficult to determine which neurological deficits persist into adulthood and which deficits improve with age.

Current Study

The purpose of the present study was to examine quantitative differences in visual attention and distractibility in college students with varying levels of ADHD symptoms. This study examined three relationships, the predictions for which were as follows. First, as suggested by previous research on this population, it was expected that students with higher ADHD levels would spend less time looking at the designated target and would glance away from the target more frequently than those with lower levels of ADHD symptoms, as measured via eye tracking during the CPT task. Second, it was predicted that all students would perform worse on the CPT task when interstimulus intervals (ISIs) are inconsistent. Finally, using past research as a guide, it was predicted that inconsistent ISIs would impact the performance of students with higher levels of ADHD symptoms more severely than they impact the performance of students with lower levels of ADHD.

Method

Participants

Thirty Appalachian State University students participated in this study. Data from 7 participants were not used because of technical issues or the participant moving too much during the experiment, leaving 23 participants to be analyzed in this study. Participants were 52% male and ranged from 18 to 21 years old ($M = 18.83$, $SD = 1.03$; see Table 1 for more demographic information). Participants were recruited through the Psychology Department SONA online research recruitment system at Appalachian State. Students received course credit for participating.

Materials and Measures

Measures of ADHD symptoms and related impairment. The Barkley Adult ADHD Rating Scale-IV (BAARS-IV; Barkley, 2011) was used to measure ADHD symptoms. The BAARS-IV is a self-report questionnaire of symptoms of ADHD. Current symptoms data was analyzed for this study. In that section, participants circled a number from one to four (1 = Never or rarely; 4 = Very often) indicating how much each statement applied to them over the past six months (e.g., "I had difficulty organizing tasks and activities"). There are 18 questions: nine questions about inattention, five questions for hyperactivity, and four for impulsivity. In addition, there is a question in which the participant marks the settings in which he or she has experienced impairment (i.e., school, home, work, and/or social life). The number of marks was added together to get a total number of settings of impairment, ranging from zero to four. The total number of settings of impairment was used as a proxy measure of the degree of ADHD-related impairment that participants currently experience. If participants normally took ADHD medication, they were asked to report their symptoms on the scale as if they were off of their medication. Internal reliability for the BAARS-IV in this study was good (Cronbach's alpha, α = .92).

Measures of depression, anxiety, and stress. Depression, anxiety, and stress symptoms were measured in order to account for the possibility of these symptoms confounding the eye-tracking data. To measure these symptoms, I used the 21-question Depression Anxiety Stress Scales (DASS-21; Brown, Chorpita, Korotitsch, & Barlow, 1997). The DASS-21 has seven, four-point items for each factor (i.e., depression, anxiety, and stress). For each question, participants circled a number from zero to three indicating how much each statement applied to them over the past week (e.g., “I found it difficult to relax”). The DASS-21 has been found to have good validity and reliability (Sinclair et al., 2012). Internal reliability for the DASS-21 in this study was good ($\alpha = .90$).

Continuous performance task (CPT). Participants were given two computer-administered CPTs, both administered on a LCD computer screen at a distance of approximately 30 inches from the monitor. The CPTs were adapted from the Conners' Continuous Performance Test 3rd Edition (C-CPT-3; Folsom & Levin, 2013). The first was a standard CPT and the second was a CPT with intermittent distractors (data for the CPT with distractors was not analyzed in this report).

Basic CPT. Participants were instructed to stare at a fixation point on the center of the screen. At certain time intervals, a letter from A to Z would appear at the fixation point for a duration of 250 milliseconds (ms). Participants were instructed to press the spacebar whenever any letter except for "X" appeared. If the target stimulus "X" appeared, participants were to refrain from pressing any button. The target “X" appeared at the rate of 10% across all trials, and the order of letters presented to participants was standardized. The size of the letters was around 2 inches.

Before the beginning of the task, there was a one-minute practice period. The task lasted around 22 minutes and consisted of 400 trials, with one trial being defined as the period of one letter presentation and the subsequent inter-stimulus interval (ISI). The task was divided into four blocks. In the first and third blocks ISIs were consistent, with two-second durations. In the second and fourth blocks ISIs were inconsistent and ranged from one to four seconds long, with an average of two seconds.

CPT with distractors. The second CPT had the same parameters as the first CPT, except that distracting letters were also presented intermittently in addition to the task letters. Distractors appeared above, below, to the left, or to the right of the fixation point, at a distance of approximately 5.5° from the fixation point. Distractors appeared during ISIs, at variable amounts of time after target letter presentations. They appeared pseudo-randomly, at a frequency of once every two to four trials (every three trials on average). Distractors were the same size and duration as the target letters. Data from the CPT with distractors was not analyzed in the current study, but rather will be used in a different study.

Eye-tracking technology. During the CPT tasks, an infrared (IR) camera was used to record eye movements. The camera uses an LED illuminator to shine IR light onto the eyes. The IR camera then detects the eye and records the position of the pupil over time. The eye-tracking program used in this study was EyeLink. For the task, participants sat in a chair, placing their forehead and chin on a headrest in order to minimize data invalidation due to head movement. During the calibration, an accuracy threshold of 1.0º was used: in order to be able to collect data for a participant, administrators of the task were required to calibrate the camera so that the least accurate point in the visual field had no more than 1.0º of error.

Measures of eye movements. Eye movements were assessed using two measures: percent time on target (i.e., percent of time spent looking at the fixation point while the target was present) and number of off-target glances. An off-target glance was defined as any time during which the participant's eye was looking at a location other than the fixation point for at least 100 ms. Eye movement data was also compared between blocks with fixed and variable ISIs to determine whether ISI type had an effect on eye movements.

Procedure

Participants were asked not to take any ADHD medication on the morning of the study. They were reminded via email the day before the study. After obtaining verbal informed consent for the study, participants filled out a demographic form which asked basic demographic information, how many hours the participant had slept the previous night, a 10-point self-report question of tiredness, and whether they had taken ADHD medication that day. If they had taken ADHD medication that day, they were rescheduled to participate in the study on a different date. After the demographic form, participants completed the DASS-21 and the BAARS-IV.

Participants were then instructed on how to complete the CPT tasks. After completing a one-minute practice session, they completed the basic CPT. In order to avoid cognitive fatigue between the two CPTs, they then did a 5-minute break activity which consisted of reading a passage taken from the book The Little Prince (Saint-Exupéry, 1943/2009). They then completed the CPT with distractors. Eye tracking was conducted during the CPT tasks to examine possible visual attentional differences. Once finished, participants were debriefed.

Data Analysis

See Table 1 for descriptive statistics for demographics, independent variables, and eye movement data. See Table 2 for two-tailed Pearson correlations between all independent and dependent variables, as well as tiredness and DASS-21 scores. After descriptive and correlational statistics were obtained, SPSS (SPSS Version 24.0; IBM, 2016) was used to analyze the data using a series of six multiple regressions in which current ADHD scores (i.e., the sum of the score for all 18 questions on the BAARS-IV), the number of settings of ADHD-related impairment, self-reported tiredness (from the demographic form), and the three factors of the

DASS-21 (i.e., depression, anxiety, and stress) were used as predictor variables. The six multiple regressions were performed with dependent variables as follows: (1) percent of time on target for all blocks; (2) number of off-target glances for all blocks; (3) percent of time on target for fixed ISI; (4) percent of time on target for variable ISI; (5) number of off-target glances for fixed ISI; (6) number of off-target glances for variable ISI.

Results

Descriptive statistics and two-tailed Pearson correlations can be found in Table 1 and Table 2. See Table 3 for a summary of regression analysis results.

Percent Time on Target - All Blocks

The multiple regression model (explained in *Data Analysis*, above) explained 66% of the total variance in percent time looking at the target area during the entire CPT task, $F(6, 16) = 5.263$, $p = .004$. However, total ADHD score was not a significant predictor of time on target (standardized beta estimate, $\beta = 0.215$, $p = .472$). In contrast, the number of settings in which ADHD-related impairment was experienced was a significant negative predictor of time on target ($\beta = -.577$, $p = .026$), such that a higher number of settings of impairment predicted lower time on target. Stress actually had the highest prediction strength for time on target ($\beta = -.984$, p $= .014$); stress predicted a lower percent of time on target. All other variables had no significant predictive relation to percent of on-target gazing.

Number of Off-target Glances - All Blocks

The multiple regression model explained 53% of the total variance in the number of off-target glances for all four blocks of the CPT combined, $F(6, 16) = 3.015$, $p = .036$. As hypothesized, the number of settings of ADHD-related impairment was a significant *positive* predictor of number of off-target glances (β = .810, *p* = .01), such that a higher number of settings of impairment predicted a lower number of off-target glances. Interestingly enough, total ADHD score was a significant *negative* predictor of number of glances (β = -.975, *p* = .012); in other words, higher current ADHD symptom levels predicted a *lower* number of off-target glances. All other predictor variables had no significant association with off-target glances across interval conditions.

Percent Time on Target - Fixed ISI vs. Variable ISI

The multiple regression model explained 64% of the total variance in percent time looking at the target for the fixed ISI (*F*(6, 16) = 4.840, *p* = .005), and 53% of the total variance for the variable ISI (*F*(6, 16) = 2.965, *p* = .038). For the fixed ISI, the only variable that significantly predicted the percentage of time on target was stress, with a negative relation (β = -.848, *p* = .035). Neither ADHD scores (β = -.115, *p* = .706) nor number of settings of ADHD-related impairment (β = -.292, *p* = .244) were significant predictors of percent time on target for the variable ISI.

For the variable ISI, number of settings of ADHD-related impairment was the only significant predictor of percent time looking at the target, with a negative relation (β = -.795, *p* = .012). Stress was a nearly significant negative predictor of percent time on target (β = -.895, *p* = .051). ADHD scores were not a significant predictor of percent time on target (β = .590, *p* = .107).

Number of Off-target Glances - Fixed ISI vs. Variable ISI

The multiple regression model explained 59% of the total variance in off-target glances for the fixed ISI (*F*(6, 16) = 3.851, *p* = .014), and 46% of the total variance for the variable ISI

($F(6, 16) = 2.276$, $p = .088$). For the fixed ISI, number of settings of ADHD-related impairment was a significant positive predictor of off-target glances ($\beta = .839$, $p = .005$). On the contrary, ADHD scores were a significant *negative* predictor of off-target glances ($\beta = -.997$, $p = .007$); in other words, higher levels of ADHD symptoms predicted a *lower* number of off-target glances. All other predictor variables were insignificant.

The same results were found for the variable ISI as for the fixed ISI. In the variable ISI, number of settings of ADHD-related impairment was a significant positive predictor for off-target glances ($\beta = .761$, $p = .021$), while total ADHD score was a significant *negative* predictor of off-target glances ($\beta = -.928$, $p = .023$); in other words, higher levels of ADHD symptoms predicted a *lower* number of off-target glances, but breadth of impairment predicted *more* off-target glances. All other predictor variables were insignificant.

Discussion

The data from the current study provides mixed results in regards to whether ADHD severity predict deficits in visual attention performance. The number of settings of ADHD-related impairment showed the most relation to visual attention. This variable was a significant predictor of eye-tracking performance for five of the six regression analyses that were run. The only regression for which the number of settings of impairment was not significant was the percent of time on target for blocks with fixed ISIs.

ADHD scores were a consistently significant negative predictor of visual attention in terms of the number of off-target glances; higher ADHD symptom severity predicted a lower number of off-target glances. However, ADHD scores did not significantly predict the percentage of time looking at the target. These findings suggest that, to a certain extent, higher levels of ADHD symptoms predict *increased* visual attention.

Possible Explanations

Those with higher ADHD symptoms may have tried harder in the task in order to compensate for their deficits. The simple CPT was relatively long (22 minutes), so it might have been that those with higher ADHD symptom levels remained vigilant for longer than those with lower ADHD levels. However, research of adults with ADHD shows consistent deficits in sustained attention (Schoechlin & Engel, 2005). If previous research holds true, one would expect ADHD symptoms to be *negatively* associated with visual attention ability, contrary to the results from the current study that found a positive association between ADHD symptoms and visual attention.

Past research has found that young adults with ADHD tend to underreport their symptoms, whereas young adults without ADHD tend to overreport symptoms of ADHD (Sibley et al., 2012). Thus, another explanation for the relationship between ADHD symptom severity and visual attention may be because the self-reported levels of ADHD symptoms may underestimate the range of ADHD levels for the sample. This would lead to exaggerated associations found between the IVs and DVs. Therefore, what may truly not be a significant positive association between ADHD symptom severity and visual attention ability may have become exaggerated enough to cross the line of significance.

The positive association between the number of settings of ADHD-related impairment and visual attention measures in this study supports predictions. ADHD impairment serves as a second measure of ADHD severity; people with a large extent of impairment due to ADHD are likely to have more severe ADHD symptoms, regardless of potentially inaccurate self-reports of ADHD symptoms.

Potential Confounds

For the ADHD questionnaire, participants that regularly take ADHD medication were told to answer the questions based on how they feel and act when not taking their medication. For those who have taken medication every day for a long time, they may have had to rely on memory or guesswork to estimate their symptoms, and, perhaps, this subset would be even more likely to *underestimate* the severity of their ADHD symptoms. However, it is not clear whether this is the case, as participants were not asked to report actual ADHD diagnosis or medication use in this study.

Technical issues with the eye-tracking camera may also have impacted the final results. Sometimes it took several rounds of calibration before the camera picked up an eye accurately enough to meet the standards of accuracy set in the beginning of the study. Camera inconsistency might have led to some of the participants' visual fixations being registered as off-target when they were actually looking on-target, and vice-versa. In addition, for some of the participants, the camera stopped tracking their eye for 10 to 30 seconds during the task, before recognizing the eye again. This resulted in the loss of data for the period that the camera was not tracking the eye. It also may have distracted the participant and caused them to be less vigilant for the remainder of the task.

Limitations/Suggestions for Future Research

This study ran regressions to determine the effect of ADHD levels on visual attention performance for all blocks, for only fixed-ISI blocks, then for only variable-ISI blocks. However, I did not run any statistics directly testing the interaction effects of ADHD x ISI type on visual attention performance. Future research could run multi-level regressions with ADHD levels, ISI type, and interaction terms in separate blocks; such a strategy would allow detection of possible ADHD x ISI type interactions and have the added benefit of actually increasing statistical power, as one model could examine ISI-type influence as well as the three models used per dependent variable in the current study.

Several limitations pertaining to ADHD medication use exist. Since participants did not answer any questions about how much or how often they take ADHD medication, there may have been a certain amount of variability in visual attention performance due to variability in frequency of medication use, as well as the effectiveness of having participants not take medication on the day of the study. If someone had taken ADHD medication every day for several years and they did not take it on the day of the study, they may have performed worse on the attention task due to not being accustomed to being off of their medication; on the other hand, someone who takes their medication only on school days may be used to the symptoms they experience when not on their medication. In addition, some participants may have in fact taken ADHD medications on the morning of the study, but told researchers that they had not. Finally, there may have been some residual ADHD medication left in participants' systems who had taken medication the day before the study.

While these weaknesses are all important to consider, the most significant limitation of this study is its low statistical power, due to its low sample size ($n = 23$). Results should be taken cautiously, as the small sample size increases the risk of committing both Type I (i.e., false positive) and Type II (i.e., false negative) errors due to variabilities from participant to participant (e.g., task administration, participant instructions, outside noises from rooms adjacent to the testing room). It is not known whether the same results would be found in a study with a larger sample size.

In addition, the current study only looked at eye movement data as a measure of visual attention ability. Future studies should use the CPT paradigm and record eye movements as well as actual performance on the CPT, including omission errors, commission errors, and reaction times. Using this information, one can examine associations between CPT performance and eye movements. For example, one could determine whether the participant was actually looking at the target while they made an error. This information could more concretely suggest whether eye-movement behavior or internal cognitive processes are more related to visual attentional issues in individuals with ADHD. Finally, it is clear that even individuals with high symptoms of ADHD are not necessarily affected by the related disorder, per se. Future research might benefit from identifying and/or recruiting individuals with clinically-diagnosed ADHD to better explore whether presence of the actual disorder is more conclusively linked to differences in eye-movement behavior during visual attention tasks.

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Table 1

Demographic, Independent, and Dependent Variables: Descriptive Statistics

Measure	*M* (*SD*) or Percentage
Age	18.83 (1.03)
Gender	52% male
Race	
White	82.6%
Latino/Hispanic	4.4%
Asian	4.4%
Middle Eastern	4.4%
Native Hawaiian/Pacific Islander	4.4%
Depression (DASS)	4.00 (3.67)
Anxiety (DASS)	4.87 (5.68)
Stress (DASS)	8.70 (8.79)
DASS Total Score	17.57 (16.07)
# Settings of Impairment	1.57 (1.31)
Total ADHD Score	31.78 (9.71)
% Time on Target	97.21 (3.33)
# Off-target Gazes	272.48 (133.68)

Table 2

Two-Tailed Pearson Correlations Between IVs, DVs, Tiredness, and DASS-21 Scores

Measure	1	2	3	4	5	6	7	8	9
1. Tiredness	-								
2. Depression (DASS)	.31	-							
3. Anxiety (DASS)	.29	.45*	-						
4. Stress (DASS)	.50*	.55**	.81**	-					
5. DASS Total Score	.45*	.69**	.90**	.96**	-				
6. # Settings of Impairment	.45*	.19	.41	.37	.39	-			
7. Total ADHD Score	.43*	.44*	.60**	.73**	.71**	.68**	-		
8. % Time on Target	-.44*	-.39	-.50*	-.70**	-.65**	-.59**	-.64**	-	
9. # Off-target Gazes	.42*	.08	.24	.18	.20	.44*	.03	-.35	-

* $p < .05$, ** $p < .01$

Table 3

Summary of multiple regression statistics for DVs "Percent Time on Target" and "Number of Off-target Glances"

		All Blocks	Fixed ISI	Variable ISI
% Time on Target	ADHD Score	n.s.	n.s.	n.s.
	# Settings of Impairment	$\beta = -.577, p = .026$	n.s.	$\beta = -.795, p = .012$
	Stress	n.s.	$\beta = -.848, p = .035$	$\beta = -.895, p = .051$
	Tiredness	$\beta = -.984, p = .014$	n.s.	n.s.
# of Off-target Gazes	ADHD Score	$\beta = -.975, p = .012$	$\beta = -.997, p = .007$	$\beta = -.928, p = .023$
	# Settings of Impairment	$\beta = .810, p = .01$	$\beta = .839, p = .005$	$\beta = .761, p = .021$
	Stress	n.s.	n.s.	n.s.
	Tiredness	n.s.	n.s.	n.s.

Note: β = standardized beta estimate. The effect of stress on % Time on Target for the variable ISI is included because it is near the threshold of statistical significance.

Appendix A

IRB Letter of Approval

To: Zachary Saint
Psychology
CAMPUS EMAIL

From: Dr. Andrew Shanely, IRB Chairperson
Date: 10/8/2017
RE: Notice of IRB Approval by Expedited Review (under 45 CFR 46.110)

STUDY #: 17-0327
STUDY TITLE: Eye Movement, Visual Attention, and ADHD Traits
Submission Type: Initial
Expedited Category: (4) Collection of Data through Noninvasive Procedures Routinely Employed in Clinical Practice,(6) Collection of Data from Recordings made for Research Purposes
Approval Date: 10/08/2017
Expiration Date of Approval: 10/07/2018

The Institutional Review Board (IRB) approved this study for the period indicated above. The IRB found that the research procedures meet the expedited category cited above. IRB approval is limited to the activities described in the IRB approved materials, and extends to the performance of the described activities in the sites identified in the IRB application. In accordance with this approval, IRB findings and approval conditions for the conduct of this research are listed below.

Study Regulatory and other findings:

The IRB waived the requirement to obtain a signed consent form for some or all subjects because the only record linking the subject and research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality. Each subject will be asked whether the subject wants documentation linking the subject with the research, and the subject's wishes will govern.

Appendix B

Participant Information Form (waived Informed Consent form)

Information to Consider about this Research

Eye Movement, Visual Attention, and ADHD Traits

Principal Investigator: Zach Saint
Faculty Advisor: Will Canu
Co-Investigator: Chris Dickinson
Psychology Department, Appalachian State University

You are invited to participate in a research study that is examining visual attention and eye movements in college students with different levels of attention-deficit/hyperactivity disorder (ADHD) traits. Anyone at least 18 years of age may apply, regardless of whether or not you have ADHD.

If you agree to be part of the research study you will be asked to perform **two simple, computer-administered attention tasks** while having your **eye movements recorded** using infrared (IR) light. Both tasks involve looking at a screen and pressing a button when a certain letter appears. During the second task, distracting letters will also appear on the screen. Some distractors may blink slowly or move across the screen. In addition to the attention tasks, you will be given a 5-minute questionnaire to measure symptoms of anxiety and depression, as well as a short questionnaire to measure ADHD symptoms. All data will remain confidential: your answers to the questionnaires will be stored in a locked private lab room, and your results on the eye-tracking task will be stored confidentially on an encrypted, password-protected USB drive.

There is no direct personal benefit to participating in this study. You will not be paid for your participation in this study. However, **you will earn 3 ELC credits for your participation.** There are other research options and non-research options for obtaining extra credit or ELC's. One non-research option to receive 1 ELC is to read an article and write a 1-2 page paper summarizing the article and your reaction to the article. More information about this option can be found at: psych.appstate.edu/research. You may also wish to consult your professor to see if other non-research options are available.

Risks and discomforts are unlikely and minimal. You will be putting your chin on a chin rest for the duration of the two tasks (20 minutes each) in order to avoid any head movements that would obscure the eye-movement data. The study will take no more than 90 minutes in total. The eye-tracking technology projects infrared (IR) light onto the eyes. An IR camera picks up the reflection of the IR light off of the eyes in order to see where the eyes are looking.

The video camera used by the EyeLink 1000 eye tracker to record and track the locations of observers' gaze requires that the eyes are illuminated. To accomplish this, the video camera assembly includes light-emitting diodes (LEDs) that emit infrared (IR) radiation at a wavelength of 890 nm (considered in the range of Class A IR radiation). The EyeLink CL illuminators are compliant with the IEC-60825-1 LED safety standard as a Class 1 LED device. This standard has been or is in the process of being adopted by most countries, and regulates many aspects of LED and laser eye safety, including retinal, corneal and skin safety. Class 1 products are "safe under reasonably foreseeable conditions of operation, including the use of optical instruments for intrabeam viewing" (EyeLink 1000 User Manual version 1.4.0, Copyright © 2005–2008, SR

Research Ltd). The amount of radiant energy used to illuminate each eye has been calculated to be less than 1 mW/cm2. This amount of IR radiation conforms to the standards set forth by numerous organizations (see attached Declaration of Conformity from SR Research, Inc.). The amount of radiant energy emitted by the IR LEDs is less than the recommended maximum exposure level, which suggests that the radiant energy from these IR LEDs poses no health risks to observers. EyeLink video-based eye tracking systems have been in use since 1995 without any reports of adverse effects and are used in laboratories worldwide.

Participating in this study is completely voluntary. Even if you decide to participate now, you may change your mind and stop at any time. You may choose not to answer any survey question for any reason. Refusal to participate or a decision to discontinue participation at any time will involve no penalty or loss of benefits to you as a participant.

If you have questions about this research study, you may contact Zach Saint or Will Canu.

By continuing to the research procedures, I acknowledge that I am at least 18 years old, have read the above information, and agree to participate.

This research project has been approved on 10/8/2017 by the Institutional Review Board (IRB) at Appalachian State University. This approval will expire on 10/7/2018 unless the IRB renews the approval of this research.

Appendix C

Demographic Information Form

1. Please write your age: __________
2. To which gender identity do you most identify? Please mark one.
   - ❏ Male
   - ❏ Female
   - ❏ Transgender
   - ❏ Gender Non-Conforming/Non-Binary
   - ❏ Not listed (print gender): _________________
   - ❏ Prefer not to answer
3. Which of these options most closely represents your racial heritage? Please mark all that apply.
   - ❏ White or Caucasian
   - ❏ Black or African American
   - ❏ Latino or Hispanic
   - ❏ American Indian or Alaska Native
   - ❏ Asian Indian
   - ❏ Native Hawaiian or Pacific Islander
   - ❏ Chinese
   - ❏ Japanese
   - ❏ Korean
   - ❏ Vietnamese
   - ❏ Filipino
   - ❏ Other Asian (print race): ____________
   - ❏ Race not listed (print race): ___________________
   - ❏ Prefer not to answer
4. Approximately how many hours did you sleep last night? _______
5. How tired do you feel right now? Please circle the number that best applies. (1 means "Not tired at all;" 10 means "Extremely tired")

   1 2 3 4 5 6 7 8 9 10
6. This morning, did you take any medication that treats ADHD symptoms (e.g., Adderall, Vyvanse, Ritalin, Concerta, Strattera, Clonidine, Wellbutrin, etc.)? Please circle "yes" or "no." Yes No

Appendix D

Depression Anxiety Stress Scales (DASS-21)

DASS 21

(OFFICE USE) Pariticipant #: *Date:*

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

1	I found it hard to wind down	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I found it difficult to work up the initiative to do things	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I experienced trembling (eg, in the hands)	0	1	2	3
8	I felt that I was using a lot of nervous energy	0	1	2	3
9	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting agitated	0	1	2	3
12	I found it difficult to relax	0	1	2	3
13	I felt down-hearted and blue	0	1	2	3
14	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
15	I felt I was close to panic	0	1	2	3
16	I was unable to become enthusiastic about anything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3

18	I felt that I was rather touchy	0	1	2	3
19	I was aware of the action of my heart in the absence of physical exertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life was meaningless	0	1	2	3

Appendix E

Depression Anxiety Stress Scales (DASS-21): Scoring Sheet

DASS 21 (OFFICE USE ONLY) Scoring Template

Total Scores (sums multiplied by 2):

D: ______

A: ______

S: ______

S
A
D
A

D
S
A
S
A

D
S
S
D
S

A
D
D
S

	A
	A
	D

Apply template to both sides of sheet and sum scores for each scale.
For short (21-item) version, multiply sum by 2.

Appendix F

Barkley Adult ADHD Rating Scales (BAARS-IV): Current Symptoms

BAARS-IV: Self-Report: Current Symptoms

Name: ______________________ Date: ______________

Sex: (Circle one) Male Female Age: ________

Instructions

For the first 27 items, please circle the number next to each item below that best describes your behavior **DURING THE PAST 6 MONTHS.** Then answer the remaining three questions. Please ignore the sections marked "Office Use Only."

Section 1 (Inattention)	Never or rarely	Some-times	Often	Very often
1. Fail to give close attention to details or make careless mistakes in my work or other activities	1	2	3	4
2. Difficulty sustaining my attention in tasks or fun activities	1	2	3	4
3. Don't listen when spoken to directly	1	2	3	4
4. Don't follow through on instructions and fail to finish work or chores	1	2	3	4
5. Have difficulty organizing tasks and activities	1	2	3	4
6. Avoid, dislike, or am reluctant to engage in tasks that require sustained mental effort	1	2	3	4
7. Lose things necessary for tasks or activities	1	2	3	4
8. Easily distracted by extraneous stimuli or irrelevant thoughts	1	2	3	4
9. Forgetful in daily activities	1	2	3	4
Office Use Only (Section 1) Total Score ________ Symptom Count ________				

Section 2 (Hyperactivity)	Never or rarely	Some-times	Often	Very often
10. Fidget with hands or feet or squirm in seat	1	2	3	4
11. Leave my seat in classrooms or in other situations in which remaining seated is expected	1	2	3	4
12. Shift around excessively or feel restless or hemmed in	1	2	3	4
13. Have difficulty engaging in leisure activities quietly (feel uncomfortable, or am loud or noisy)	1	2	3	4
14. I am "on the go" or act as if "driven by a motor" (or I feel like I have to be busy or always doing something)	1	2	3	4
Office Use Only (Section 2) Total Score ________ Symptom Count ________				

(cont.)

From *Barkley Adult ADHD Rating Scale–IV (BAARS-IV)* by Russell A. Barkley. Copyright 2011 by The Guilford Press. Permission to photocopy this form is granted to purchasers of this book for personal use only (see copyright page for details).

BAARS-IV: Self-Report: Current Symptoms *(page 2 of 3)*

Section 3 (Impulsivity)	Never or rarely	Some-times	Often	Very often
15. Talk excessively (in social situations)	1	2	3	4
16. Blurt out answers before questions have been completed, complete others' sentences, or jump the gun	1	2	3	4
17. Have difficulty awaiting my turn	1	2	3	4
18. Interrupt or intrude on others (butt into conversations or activities without permission or take over what others are doing)	1	2	3	4
Office Use Only (Section 3) Total Score ________ Symptom Count ________				
Section 4 (Sluggish Cognitive Tempo)	**Never or rarely**	**Some-times**	**Often**	**Very often**
19. Prone to daydreaming when I should be concentrating on something or working	1	2	3	4
20. Have trouble staying alert or awake in boring situations	1	2	3	4
21. Easily confused	1	2	3	4
22. Easily bored	1	2	3	4
23. Spacey or "in a fog"	1	2	3	4
24. Lethargic, more tired than others	1	2	3	4
25. Underactive or have less energy than others	1	2	3	4
26. Slow moving	1	2	3	4
27. I don't seem to process information as quickly or as accurately as others	1	2	3	4
Office Use Only (Section 4) Total Score ________ Symptom Count ________				
Total Scores for Entire Scale: Sum of Sections Raw Scores 1–3—Total ADHD Score ________ Section 1 Symptom Count ________ Sum of Sections 2 and 3 Symptom Counts ________ Total ADHD Symptom Count ________ (Sum of 1–3) SCT Symptom Count ________				

(cont.)

BAARS-IV: Self-Report: Current Symptoms *(page 3 of 3)*

Section 5

28. Did you experience *any* of these 27 symptoms at least "Often" or more frequently (Did you circle a 3 or a 4 above)? **No** **Yes** (Circle one)

29. If so, how old were you when those symptoms began? (Fill in the blank)
I was ___________ years old.

30. If so, in which of these settings did those symptoms impair your functioning? Place a *check mark* (✓) next to all of the areas that apply to you.

___________ School
___________ Home
___________ Work
___________ Social Relationships

Note. Items 1–18 are adapted with permission from the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision.* Copyright 2000 by the American Psychiatric Association.