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The Effects of Stimulant Medication on Reaction Time in Recreationally Active Individuals with Attention Deficit Hyperactivity Disorder

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THE EFFECTS OF STIMULANT MEDICATION ON REACTION TIME IN RECREATIONALLY ACTIVE INDIVIDUALS WITH ATTENTION DEFICIT HYPERACTIVITY DISORDER

by

NICHOLE LAFORTUNE

(Under the Direction of Tamerah Nicole Hunt)

ABSTRACT

Context: Participants with Attention Deficit Hyperactivity Disorder (ADHD) have shown cognitive impairments that affect coordination, anticipation and planning. In the ADHD population, stimulant medication has shown to have beneficial outcomes for 75% of the people. Unfortunately, in most research, patients with ADHD are excluded and little is known about this population.
Purpose: Determine the effects of stimulant medication in recreationally active ADHD participants on reaction time.
Design: Cross-section between groups design
Methods: Participants were divided into two groups (ADHD and controls). Upon arrival to the Biomechanics Lab participants performed two tests, Mode A and Mode D on the Dynavision D2 (Dynavision International LLC, 2016). Mode A consisted of three practice trials, followed by five test trials. Mode D consisted of one practice trial, followed by seven test trials for each of the three tasks. After completion of all tests, participants completed an effort debriefing. ADHD participants performed one session "on medication" and one session "off medication." The controls performed both trials at the same interval with no use of medication. Group differences were calculated using a mixed model repeated measures analysis of variance (ANOVA) using SPSS 23.0 software (SPSS Inc. Chicago, IL). Additionally, paired-sample t-tests were calculated to examine ADHD participants "on" verses "off" medication and differences in reaction time variability (RTV).
Results: 34 participants (n=21 controls, n=13 ADHD) completed all testing. A statistically significant difference existed between groups for Mode A ($F_{(1,32)}$=13.12, p=0.01, Λ=0.71, η=0.29, Cohens D= 0.94), Mode D-Direct (MDD) ($F_{(1,32)}$=5.61, p=0.015, Λ=0.85, η=0.15, Cohens D= 0.632), Mode D-Circle (MDC) ($F_{(1,32)}$=3.41, p=0.011, Λ=0.90, η=0.10, Cohens D= 0.433) and Mode D-Horizontal (MDH) ($F_{(1,32)}$=2.30, p=0.05, Λ=0.93, η=0.07, Cohens D= 0.31), with controls demonstrating faster reaction times. A statistically significant difference was found for medication use during MDC (t(12)=2.35, p=0.04), with ADHD participants demonstrating slower reaction times when off their medication. There was a statistically significant difference for RTV for MDD (t(12)=2.199, p=0.05) on and off their medication.
Conclusion: The use of stimulant medication does not appear to consistently effect reaction time performance. In a recreationally active population, participants with a self-reported diagnosis of ADHD perform slower than controls on reaction time tests.

These slower performances could be due to task complexity (inter stimulus intervals), movement patterns of ADHD participants, as well as type of ADHD. Future research should investigate ADHD in Division I college athletes in regards to reaction time (RT) and reaction time variability (RTV) and the effect of ADHD on athletic performance.

INDEX WORDS: Attention Deficit Hyperactivity Disorder, Reaction time variability, ADHD medication, Choice Reaction Test, Simple Visual Reaction Test.

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DEDICATION

I would not have been able to get through this experience of graduate school without the love and support of my family and friends. These are the people who have always pushed me to be a better person in all aspects. I would not be where I am today without each and every one of you who have impacted my life drastically.

ACKNOWLEDGMENTS

I would not have been able to successfully complete this thesis without the support of my committee. I was very fortunate to have all members on my committee that were able to help and support me through this process. I am grateful for the input and guidance received to help make this a successful document.

Additional thanks specifically to my mother for showing me how to be a strong, independent and compassionate women.

I would also like to thank my roommates for keeping me sane and on schedule.

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CHAPTER 1

INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental/ neurobehavioral disorder defined by chronic and impaired behavior patterns that cause abnormal attention, focus, hyperactivity, impulsivity, and disorganization.[1–4] ADHD can present in three different subtypes; predominantly inattentive presentation, predominantly hyperactive/impulsive presentation or a combined presentation.[1,3,5] There is no known cause of ADHD, although there are several hypotheses addressing the physiological aspects of this disorder. These hypotheses range from reduced volume and functionality of gray and white matter in the brain,[6] to reduced function of the prefrontal cortex (PFC), caudate, and cerebellum in ADHD patients.[7,8]

There appears to be a rise in the rates of ADHD diagnoses consistently since 2003. From 2003 to 2011, the rate of ADHD diagnoses in children increased from 7.8% to 11% respectively.[9] These diagnosis rates have increased on average approximately 3%-5% per year from 1997 to 2011.[9] Unlike most psychiatric disorders that are diagnosed in adulthood, ADHD is first diagnosed during childhood, however, symptoms can persist into the adolescents and adulthood years.[4] Research suggests that as high as 80% of individuals with ADHD continue to show symptoms into their adolescent and adult years.[2,10] It is estimated that 2.5% to 4.5% of adults in the United States have been diagnosed with ADHD, and 3.4% of adults worldwide demonstrate ADHD symptoms.[1,11] With such a large amount of the adult ADHD population continuing to show symptoms into the adult years make this population an interest for many research endeavors.

While there appears to be noticeable differences within the ADHD population, one important difference appears in motor performance.[12] Previous research reports children and adolescents with ADHD commonly have poor coordination, balance, and motor ability.[13–16] Research has suggested that children with ADHD may be at a higher risk for movement skill difficulties.[16] When looking at children with ADHD, in terms of fitness and fundamental gross motor skills, they are below average when compared to non-ADHD matched individuals.[15] The presence of these deficits associated with ADHD can affect motor performance and coordination having a direct impact on their ability to react. This idea of affected motor performance is interesting as again most of this research is done in the childhood and adolescent years. Which begs the question; is there motor differences in adults with ADHD? One way to assess motor differences is to do so by looking at reaction time.

Significant research has examined the effect of ADHD on reaction time. Reaction time (RT) is defined as, "the time it takes to initiate a response after a sensory stimulus has been brought about."[17] A simple reaction is a task in which an individual performs the same response to a single stimulus every trial.[18–20] A complex reaction involves more than one stimuli and/or response across different trials.[18] It is common for patients with ADHD to have slower and more variable RTs off their medication when compared to normal controls.[21,22] Reaction time distributions tend to be positively skewed especially for individuals with ADHD resulting in abnormally slower responses.[23] Additionally, individuals with ADHD show increased reaction time variability (RTV) across a large range of tasks.[24–27]

RTV is described as "an inconsistency in a person's responding speed, which is measured in seconds or milliseconds."[24–27] RTV is attributed to periodic lapses of attention, these occur randomly and periodically, causing slower responses in people with ADHD.[23,28–30] This inability

to respond could be due to the lapse in attention requiring longer reaction times.[31] Like previously stated, individuals with ADHD show increased RTV across many ranges of tasks, some include; reaction time motor speed, choice decision, vigilance, behavioral inhibition, cognitive interference, working memory, visual saccade and visual discrimination.[24–27] With the use of stimulant medication, some of these deficits have shown improvements. Once a stimulant medication has been used, there is a rapid and predictable decrease in disruptive symptoms and an increase in attentiveness shown.[32] Benefits of stimulants include attention and concentration improvements as well as fine motor coordination and balance.[10] Stimulant medications may have the ability to enhance task efficiency.[16] Stimulants have been associated with large decreases in RTV, showing that patients with ADHD significantly improve or normalize RTV. [23] With the use of ADHD medication, specifically stimulant medications, most studies show there to be an acceleration of mean RT and reduced RTV in children and adults with ADHD.[33] Further, when ADHD participants are off or discontinue stimulant medication use, they have demonstrated slower movement preparation.[22]

Drug therapy, especially stimulant treatments, are the most common and effective treatment and management of ADHD.[34–38] Approximately 56% of people with ADHD are being treated by pharmacological methods, specifically stimulant medication.[39] There are concerns about stimulant medication and their advantages for patients with ADHD compared to non ADHD population.[34] The advantages that are currently being discussed do not have to do with advantages in sport, but rather advantages in regards to school/work/social situations. One study showed that when prescribed a stimulant medication, there was a 75% improvement in behavior, academic performance, cognitive performance and socialization.[40] One study explained that children who play baseball, who take stimulant medication have admitted to having a mindset

that the medication will help improve their performance with cognition and physicality.[41] This is a perceived mindset that children have admitted to, no research has been done looking at if the adult athletic population feels there is perceived mindset of better performance.

Many studies are regularly looking at both children and adolescents in this area of research.[30] There has been little to no research looking at the adult population of people with ADHD. There is even less research done in regards to looking at people who are physically active. With that being said, some elite athletes with ADHD are perceived as having an unfair advantage in competition.[16] This perceived advantage leads to the question: "Do stimulant medications give participants with ADHD an advantage in performing in elite sports performance?" With there being no research in the ADHD population in regards to physical activity, the first step that may be necessary is to look at recreationally active individuals with ADHD and analyze differences that may be seen in RT and RTV. There is still a need for the assessment of reaction time in physically active individuals with and without ADHD, as well as, the effects of stimulant medication on fundamental movement and reaction.[16] With little research done in this area, the purpose of this study was to look at recreationally active individuals with self-reported ADHD and assess their reaction time, while on and off their medication and compare those results to a control group of typically developing recreationally active individuals.

CHAPTER 2

Methods

Participants

Participants were taken from a convenience sample of recreationally active college students. The participants were divided into two groups: a control group (n=21) and a group that self-reported a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD) (n=13). The controls came from the same recruitment process as the ADHD participants, however, they denied having a diagnosis of ADHD.

Inclusion criteria for the ADHD group: 1) 18-25 years old, 2) have a self-reported ADHD diagnosis with prescribed stimulant medication and 3) recreationally active. The inclusion criteria for the control group include: 1) 18-25 years old, 2) recreationally active and 3) must not have a diagnosis of ADHD. The exclusion criteria for controls and ADHD group include: 1) any musculoskeletal or head injury in the last 6 months, 2) patients with prescribed non-stimulant medication, 3) mental health comorbidities such as anxiety or depression, 4) prescribed medications for other comorbidities (high blood pressure, narcolepsy, asthma, etc.) 5) smokers, 6) use of alcohol or within 24 hours of testing, and 7) ADHD individuals who consistently take their medication and are unable normally function without the use of medication.

Instrumentation:

Dynavision (International LLC, 2016)

The Dynavision D2 is a light training reaction device developed to train sensory and motor integration through the visual system.[42] The Dynavision is a visuomotor training device that was used to assess the participant's reaction time. It is a 120cm x 165cm training surface that consists of 64 illuminating buttons. These buttons are arranged in five nested rings

surrounding a LCD screen located in the middle of the device.[43] The device can be raised and lowered depending on the height of the participant. The participant stands at a self-selected distance where they can easily reach all the lights and would then perform the selected tests.

There are mixed reports of Dynavision Intraclass correlation coefficient (ICC) ranges across modes. For Mode A studies, ICC values range from 0.75-0.88.[43,44] For Mode D, the ICCs vary depending on the measure (visual reaction time reliability versus motor reaction time variability). Mode D's visual reaction ICC was 0.84 and the motor reaction ICC was less at 0.63.[44] Speed and digit task techniques when using the Dynavision found a reliability of 0.71 and 0.73.[45] Initial improvements in reaction time trials when using the Dynavision have been attributed to a learning effect.[43]

Mode D (Choice Reaction Test)

Mode D has the ability to assess both motor as well as visual reaction time. Visual reaction time is measured as the amount of time it takes the participant to identify the stimulus and initiate their reaction by removing their hand from the home button. The motor response time is measured by the amount of time it takes the participant to physically strike the illuminated button as quickly as possible, after removing their hand from the home button. The amount of time between the hand leaving the home button to striking the new button is the motor reaction time.[44] The outcome of combining the motor reaction time with the visual reaction time is the physical reaction time. For the purposes of this study, we will examine physical reaction time.

Standard procedures for this test, suggest the participant complete one practice test for each of the three tasks of Mode D. The three tasks included a straight line stimulus response (Mode DH), a circle stimulus response (Mode DC) and a direct stimulus response (Mode DD).

The participant stood at a self-selected distance where they could easily reach all of the lights. This position was measured and recorded to ensure the participant was at the same position during follow-up testing. The measurements were taken from the tip of the participants toe to the base of the Dynavision board.

Before starting each of the three tasks (Mode DH, Mode DC, Mode DD), the potential responses that could be struck were displayed for the participant to see prior to the start of the test. The participant then held down the red "home" button to start the first task. Once the "home" button was held down a new stimulus appeared within 2-4 seconds of holding down the home button. Once the new stimulus appeared, the participant removed their finger from the home button and hit the new stimulus as quickly as possible. For example, during Mode DH, the participant would hold down the red home button and then respond to a single stimulus in a horizontal pattern. After each of the individual responses, the researcher wrote down the physical reaction time. After the information was recorded, the researcher instructed the participant to again hold down the home button to continue with the testing. This process was repeated for one practice trial and seven test trials. Once Mode DH was complete, the researcher then progressed to the next task by hitting the green button.

The next task consisted of the semi-circle stimulus response (Mode DC). The participant was given 20-40 seconds rest in between each of the three tasks. [43] The semi-circle stimulus response task also had one practice trial followed by seven test trials. The participant held down the home button and tried to strike the new stimulus as quickly as possible. The participant waited to proceed until they were instructed to do so by the researcher. The previously described procedures for Mode DH were followed for Mode DC, but the potential stimuli were arranged in a semi-circular pattern rather than a horizontal line. After the participant completed the semi-

circle test trials the researcher progressed by hitting the green button to reach the last task of this test program. The participant continued to Mode DD. For the direct task, the participant knew exactly which button was going to illuminate in 2-4 seconds after holding down the home button. The participant had one practice trial followed by seven trials.[44]

Mode D visual reaction time has shown strong reliability with an ICC ranging from 0.73-0.84. The motor reaction time of Mode D has moderate reliability having an ICC of 0.63. [44] Wells et al. showed no significant differences between consecutive sessions,[44] indicating there was less of a learning curve present during Mode D tasks. The absence of a learning curve could be due to the lack of task complexity with this test program.[42]

Mode A (Simple Visual Reaction Test)

Mode A has the ability to assess average RT over a one minute period. The standard test protocol for Mode A requires the participants to stand at a self-selected distance where they can easily reach all the lights and can peripherally see the lights on the outer rings. This spot was measured from the bottom of the board to the tip of the participants toe to ensure the participant was in the same position for retesting. Once the participant was in a comfortable position they were instructed that they could use both hands and were instructed to try to use either the front or the back of their hand throughout the entire test. Whichever part of their hand they decided to use for the first test session, they were instructed to use the same technique for follow-up testing. Then the testing process was ready to begin. The participant was then instructed to try to keep their eyes focused on the middle of the Dynavision looking at the LCD screen. Mode A is able to assess reaction time using mostly your peripheral vision. The researcher then counted down from five to start Mode A. With the participants eyes focused on the LCD screen, the Dynavision showed a stimulus on the board, the participant then struck the button that was red as

quickly as possible, while keeping their focus on the LCD screen. Once the stimulus had been struck, the red light relocated to another location on the board, where the participant must then strike the new stimulus at the new location as quickly as possible. This continued for a one minute period.[44] The participant had three practice trials followed by five test trials. Mode A has a moderate to strong ICC ranging from 0.68-0.75.[44]

Effort Debriefing

Following the Dynavision testing there was a simple effort debriefing (Appendix D). Within the effort debriefing, the researcher asked the participant to rank on a 0-6 scale (with zero representing they did not try at all and six representing their best effort) regarding how hard they felt they tried. This was used to assess people who did not put forth any effort and could potentially be eliminated from the study. There were also probing questions for the participants such as: "Were there any points in which you felt you stopped trying your hardest? If so, which sections?" "Did you feel as if you lost attention/interest during any of the testing sessions? If, so which sections?" "Do you feel your loss of attention/ interest affected your effort?"

Procedures:

Pilot Testing:

Pilot testing was completed prior to participant recruitment. This determined the feasibility of the test protocol and allowed competence in administration, as well as examining the participants' ease of understanding the instructions. Pilot testing was done on Division I NCAA athletes with ADHD as well as controls, with no diagnosis of ADHD. The test protocol was replicated as previously explained utilizing both Mode A and Mode D. The pilot subjects then went through the effort debriefing discussion with the researcher.

General Procedures:

Participants were recruited through flyers that were distributed and displayed in Hanner, Hollis, the Student Disabilities Resource Center (SDRC) and the student health center. Recruitment through health sciences classes was also completed to enhance recruitment numbers. Once the researcher was contacted by a potential participant, a follow up call/email was made to discuss inclusion and exclusion criteria. At this time, ADHD participants disclosed their regular medication habits regarding when they take their medication. The researcher also discussed whether the potential participant took any "medication holidays" (i.e., days they choose not to take their medication). The researcher determined the testing sessions that were considered to be "off" based upon their normal medication regiment. To have the ability to test participants with ADHD for their "off medication" trial testing either occured during a time they did not regularly take the medication or testing occurred prior to taking their normal medication intake. There were no points in the study where the researcher asked the ADHD participants to not take their medication. Their "off medication" trial was scheduled around the time of their normal medication patterns.

Once all criteria were met, the participants were enrolled in the study. Test sessions for the ADHD group were based around their medication use and controls testing sessions occurred during best availability times. Prior to the first test session, participants arrived to the biomechanics lab and filled out consent forms, as well as demographic sheets (Appendix D). The participants were assigned ID numbers, for confidentiality purposes, that only the researcher had access to decoding. When ADHD participants arrived to each session, the ADHD participants had to validate their medication use. The researcher determined if the ADHD participants had taken their medication during "on medication" trials. The researcher also

verified the “off medication” trials by asking the participants if they did not take their medicine that day. After all appropriate information was obtained, the participants performed Mode A and Mode D tests on the Dynavision. This process took approximately 20 minutes per test session.

Test sessions and test trials were counterbalanced. The medication trials were also counterbalanced for ADHD participants. This process was completed by randomly selecting ADHD participants to be “on medication” first and “off medication” for their second test trial and vice versa. This reduced the likelihood of practice effects overshadowing the medication effects. The order of testing was also counterbalanced for all participants. This was accomplished by randomly assigning the test protocols that would be performed first (Mode A or Mode D). Counterbalancing the medication trials and test protocols reduced the likelihood of finding differences as a result of only practice effect or fatigue.

After all the testing protocols were completed, there was a posttest effort debriefing. During the debriefing the researcher discussed the participant’s effort and attention/interest during the testing. A follow-up appointment for the second test session was scheduled within 48-72 hours after the first testing session. During the second test session, the participants repeated the same testing protocol. Once all the data were collected, the information was put into IBM Statistical Package for Social Sciences Software (SPSS) Statistic 23 software (SPSS Inc. Chicago, IL).

Data Analysis:

This is a cross-sectional between groups design. The independent variables for this study are group (ADHD and Controls) and the testing session (on medication verses off medication). The dependent variables were reaction time outcomes of the individual tests as well as reaction time variability.

Statistical Analysis:

Statistical analysis was calculated using IBM SPSS Statistics 23 software (SPSS Inc, Chicago, IL). Statistical assumptions that were accounted for were sphericity, independency of cases, normality, and variance of equality or homogeneity. This study used a 2 (group) x 2(time) mixed model repeated measures analysis of variance (ANOVA) to compare ADHD participants to controls. A paired-samples t-test was also run to compare ADHD participants on and off medication trials. For RTV the coefficient of variance (COV) was taken for ADHD participants for Mode A and Mode D. Then a paired-sample t-test was run to find the variability of the COV for ADHD participants on and off their medication. All alpha levels were set a *priori* at 0.05. The effect size was calculated using the partial eta squared. Prior to calculations, the researcher examined normality, outliers and assumptions.

CHAPTER 3

RESULTS

Thirty-four participants (n=13 ADHD, n=21 controls) completed this study. There was a total of 21 females and 13 males who participated in this study. Participants ranged from 18 to 24 years of age with a mean of 21.91 $\pm$ 1.69 years. The average time between test sessions ranged from 48 to 72 hours with the mean time being 53.64 $\pm$ 10.33 hours. No participants were excluded due to lack of effort, with the cut off score being a three on the effort debriefing. Eight of the thirteen participants with ADHD felt as if they had a loss of attention during testing. Of those eight, six stated that they felt their loss of attention affected their effort. For the ADHD participants the most common medications used were Adderall (5 participants) and Vyvance (5 participants). The range of use of medication for these participants ranged from one to five years of usage. Sleep for the ADHD participants ranged from five hours of sleep to nine hours of sleep. The controls had similar sleep patterns ranging from four and a half hours of sleep to nine hours of sleep. The effort ranges for test sessions and additional demographic information can be found in Table 1.

Table 1: Demographics.

Demographic	ADHD (SD)	Control (SD)
Age	21.15 (2.19)	22.38 (1.12)
Weight	73.06kg (41.26)	74.71kg (33.90)
Height	173.11 cm (9.32)	171.87 cm (13.92)
Effort	4.5-6	4-6
Males	6	7

Females	7	14

MODE A:

Significant differences between the ADHD group and controls were seen ($F_{(1,32)}$=13.12, p=0.01, Λ=0.71, η=0.29, Cohens D= 0.94) during Mode A, where controls had a faster reaction time compared to ADHD participants (Table 2, Figure 1, Figure 2). A significant difference was found for the effect of medication ($F_{(1,32)}$=13.12, p<0.001, Λ=0.71, η=0.29, Cohens D= 0.94) between ADHD and controls, with controls performing better compared to ADHD participants both on and off medication. A paired-sample t-test revealed no significant difference in ADHD participants on and off medication (t(12)=2.08, p=0.06).

Reaction time variability was calculated in the ADHD group across medication use for Mode A. A paired-sample t-test revealed no significant differences (t(12)=0.644, p=.532) in variability of patients with ADHD on and off medication for Mode A. The mean difference for Mode A was (Mon-Moff=0.014611).

Table 2: Means and Standard Deviations of Mode A.

	Group	Mean	Standard Deviation
Mode A	ADHD (OFF)	0.90	0.12
	Control	0.78	0.13
Mode A	ADHD (ON)	0.83	0.11
	Control	0.74	0.12

Mode D-Direct (MDD):

Significant differences were seen between ADHD participants and controls ($F_{(1,32)}$=5.61, p=0.015, Λ=0.85, η=0.15, Cohens D= 0.632) during Mode D-Direct, where controls had a faster reaction times compared to ADHD participants (Table 3, Figure 3, Figure 4). A significant difference was found for the effect of medication ($F_{(1,32)}$=5.61,p=0.02, Λ=0.85, η=0.15, Cohens D= 0.632) between ADHD and controls. A paired-samples t-test revealed there was no significant differences in ADHD participants on and off medication (t(12)=1.78, p=0.10).

Reaction time variability was calculated in the ADHD group across medication use for Mode DD. A paired-sample t-test revealed significant differences (t(12)=2.199, p=0.05) in variability of patients with ADHD on and off their medications for Mode DD. The mean difference for Mode D-Direct was (Mon-Moff=0.063158).

Table 3: Means and Standard Deviations of Mode D-Direct.

	Group	Mean	Standard Deviation
Mode DD	ADHD (OFF)	0.65	0.09
	Control	0.56	0.13
Mode DD	ADHD (ON)	0.60	0.12
	Control	0.52	0.08

Mode D-Circle (MDC):

Significant differences were seen between ADHD participants and controls ($F_{(1,32)}$=3.41, p=0.011, Λ=0.90, η=0.10, Cohens D= 0.433) during Mode D-Circle, where controls had a faster reaction times compared to ADHD participants (Table 4, Figure 5, Figure 6). There was no significant difference found for the effect of medication ($F_{(1,32)}$=3.41, p=0.07, Λ=0.90, η=0.10,

Cohens D= 0.433) between ADHD participants and controls. A paired-samples t-test revealed a significant difference on and off medication (t(12)=2.35, p=0.04), where ADHD participants completed reaction time tasks faster on medication (Figure 9).

Reaction time variability was calculated in the ADHD group across medication use for Mode DC. A paired-sample t-test revealed no significant differences (t(12)=0.713, p=0.489) in variability of patients with ADHD on and off their medications for Mode DC. The mean difference for Mode DC was (Mon-Moff=0.027155).

Table 4: Means and Standard Deviations of Mode D-Circle.

	Group	Mean	Standard Deviation
Mode DC	ADHD (OFF)	0.87	0.11
	Control	0.74	0.14
Mode DC	ADHD (ON)	0.80	0.06
	Control	0.72	0.15

Mode D-Horizontal (MDH):

Significant differences were seen between ADHD participants and controls ($F_{(1,32)}$=2.30, p=0.05, Λ=0.93, η=0.07, Cohens D= 0.31) during Mode D-Horizontal, where controls had faster reaction times compared to ADHD participants (Table 5, Figure 7, Figure 8). There was no significant difference found for the effect of medication ($F_{(1,32)}$=2.30, p=0.14, Λ=0.93, η=0.07, Cohens D= 0.31) between ADHD participants and controls. A paired-samples t-test revealed no significant difference in ADHD participants on and off medication (t(12)=1.18, p=0.26).

Reaction time variability was calculated in the ADHD group across medication use for Mode DH. A paired-sample t-test revealed no significant differences ($t(12)=1.148$, $p=0.273$) in variability of patients with ADHD on and off their medications for Mode DH. The mean difference for Mode DH was (Mon-Moff=0.028274).

Table 5: Means and Standard Deviation of Mode D-Horizontal.

	Group	Mean	Standard Deviation
Mode DH	ADHD (OFF)	0.78	0.11
	Control	0.69	0.15
Mode DH	ADHD (ON)	0.73	0.10
	Control	0.67	0.12

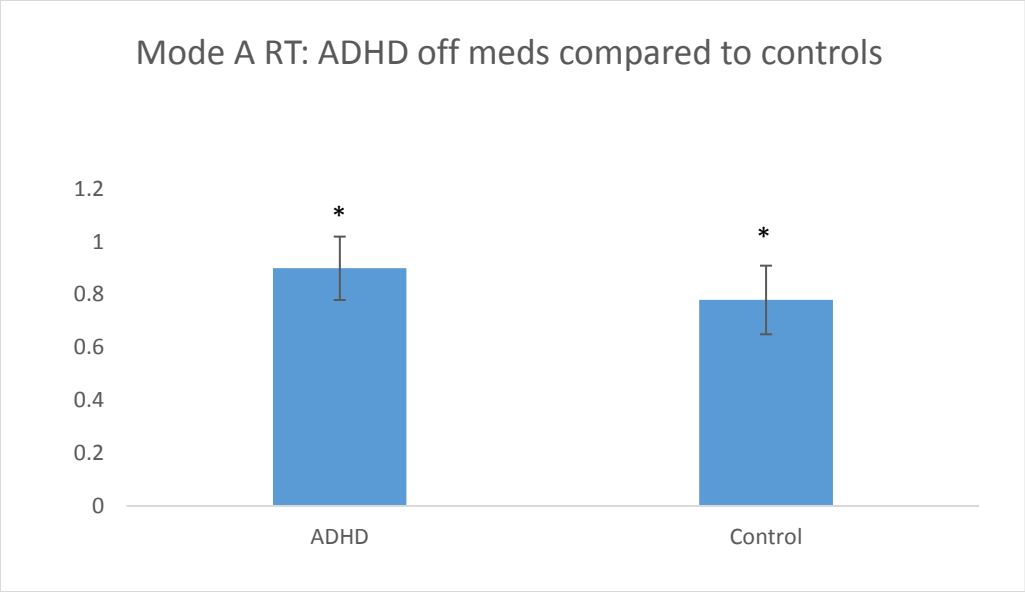

Figure 1: Mode A: ADHD participants off medication compared to controls.

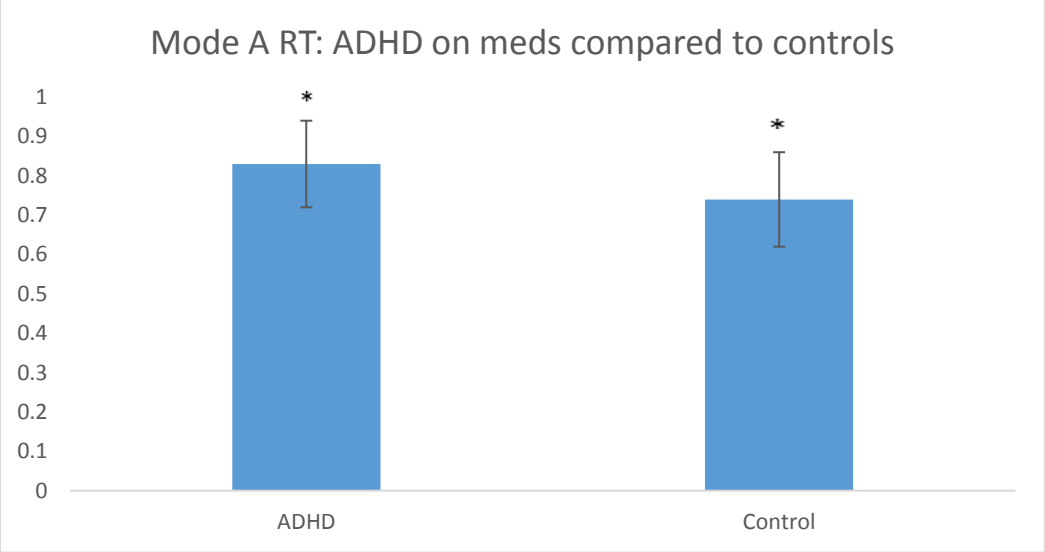

Figure 2: Mode A: ADHD participants on medication compared to controls.

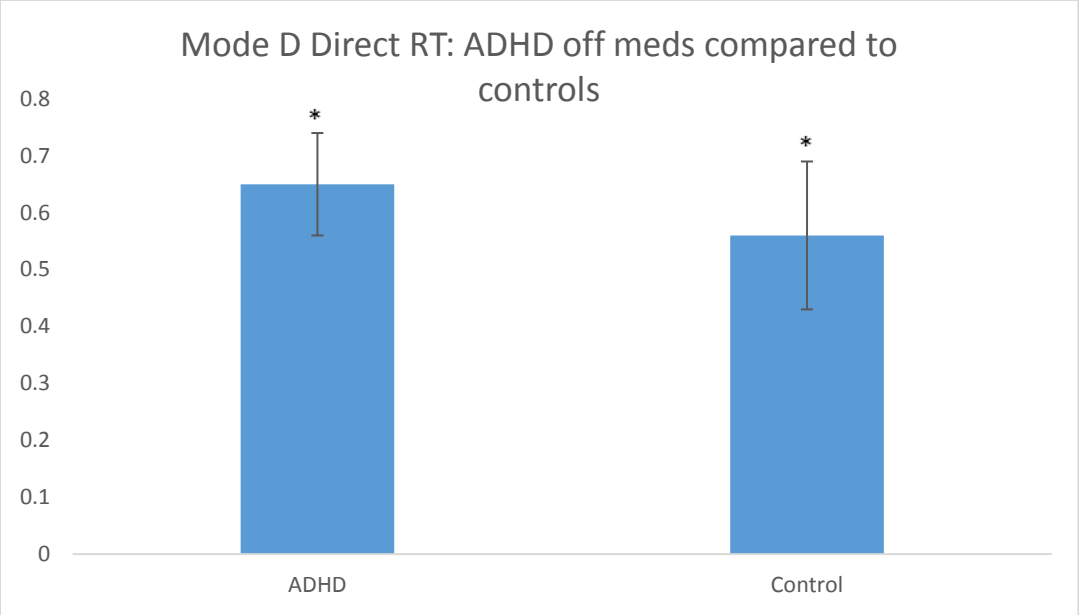

Figure 3: Mode D Direct: ADHD participants off medication compared to controls.

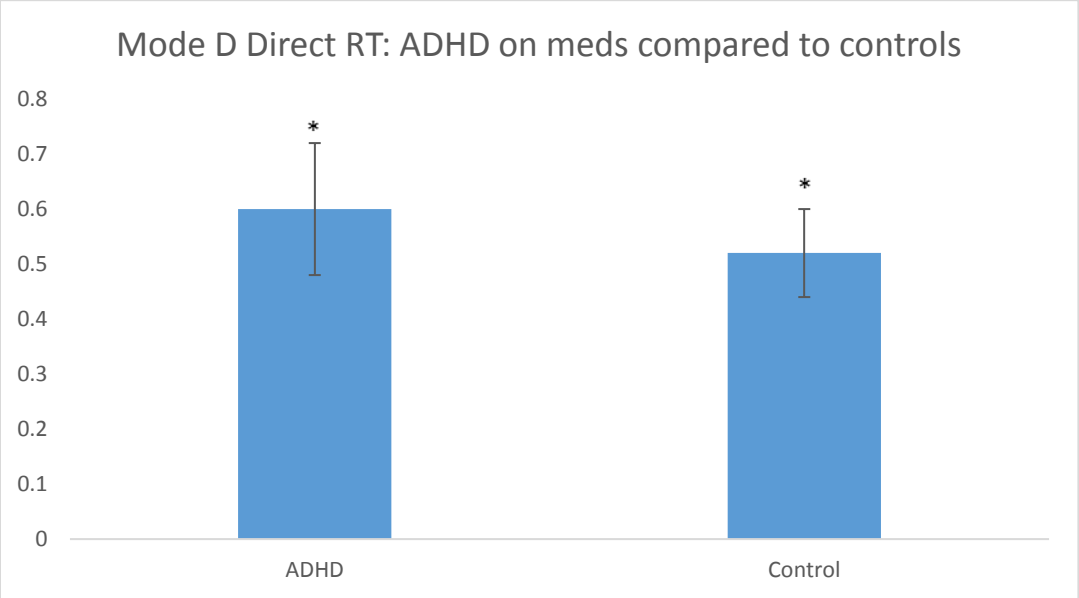

Figure 4: Mode D Direct: ADHD participants on medication compared to controls.

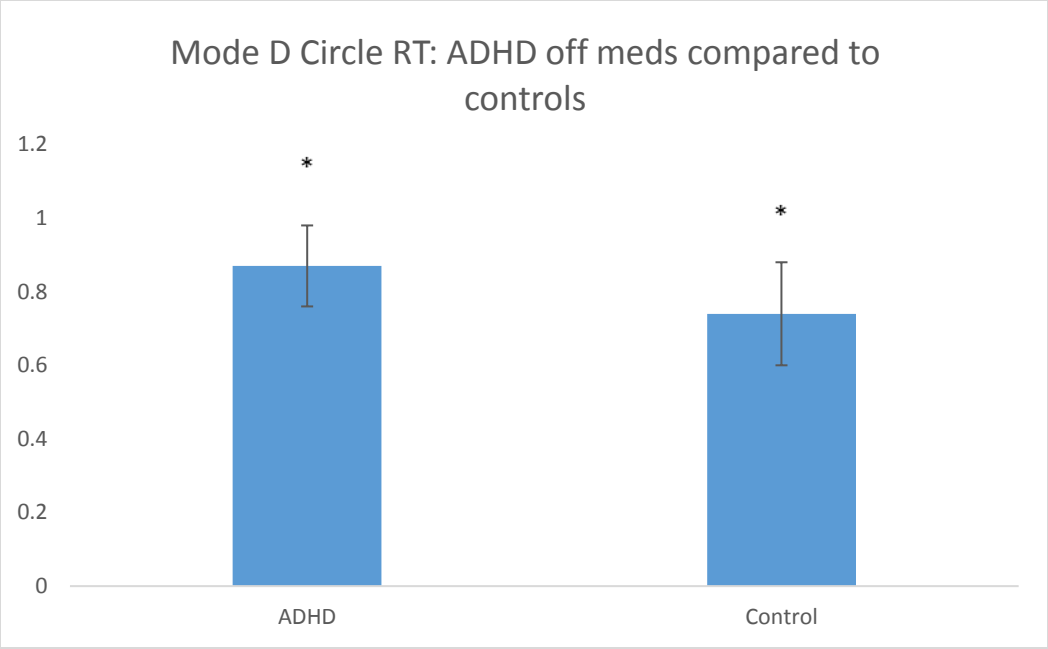

Figure 5: Mode D Circle: ADHD participants off medication compared to controls.

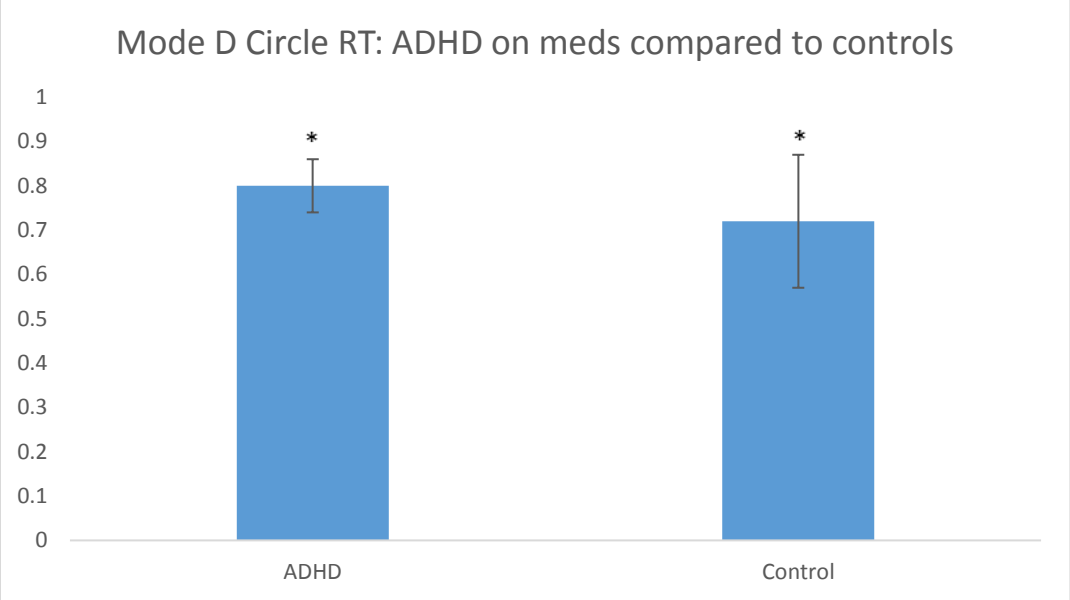

Figure 6: Mode D Circle: ADHD participants on medication compared to controls.

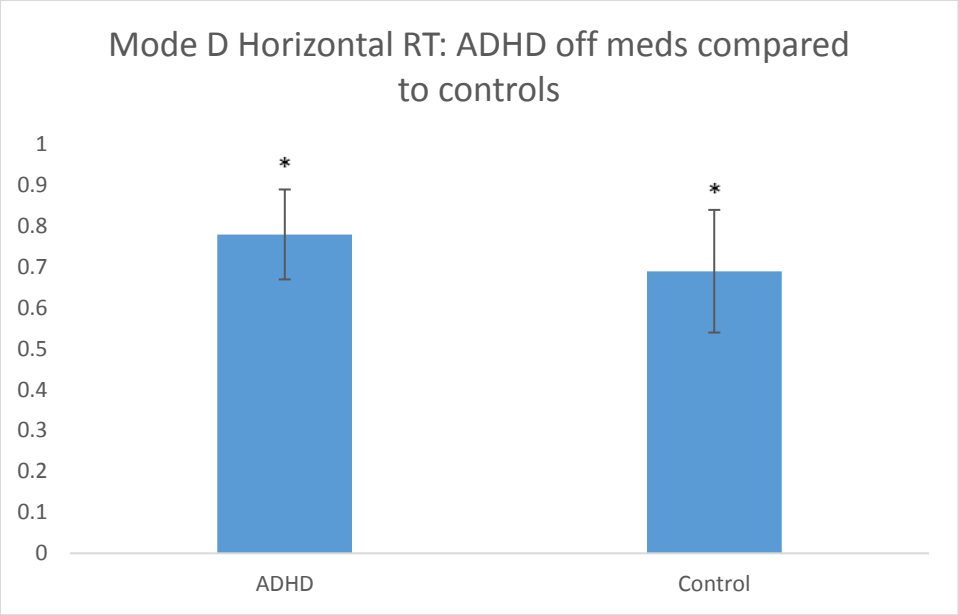

Figure 7: Mode D Horizontal: ADHD participants off medication compared to controls.

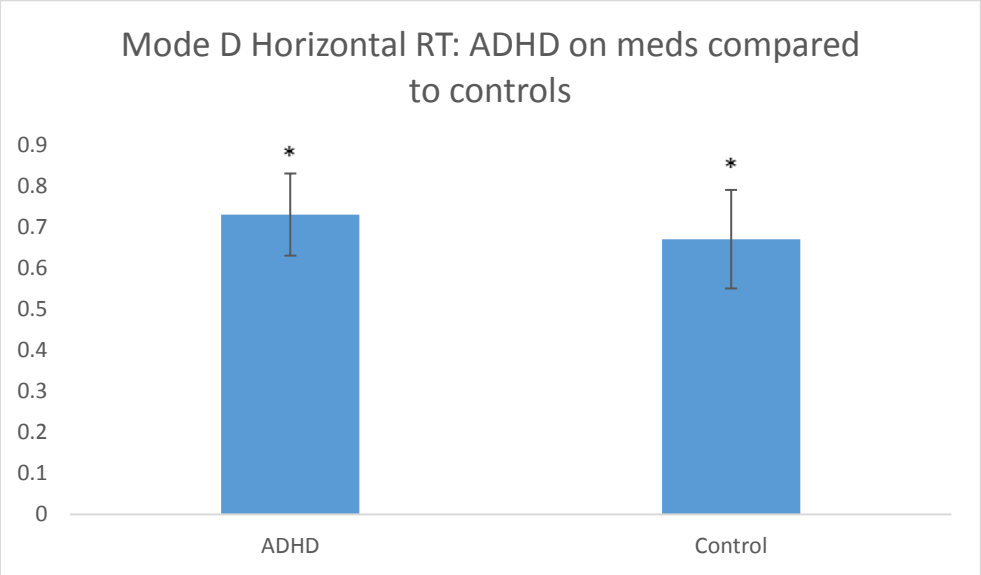

Figure 8: Mode D Horizontal: ADHD participants on medication compared to controls.

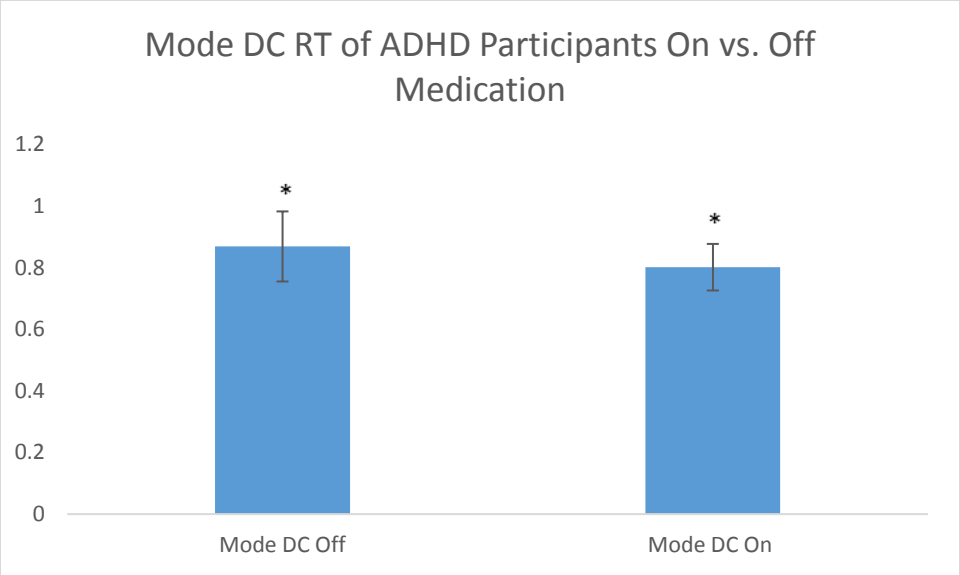

Figure 9: Comparing mean RT of ADHD participants during Mode DC on and off medication.

CHAPTER 4

DISCUSSION

The purpose of this study was to determine the effects of stimulant medication on reaction time in recreationally active individuals with self-reported Attention Deficit Hyperactivity Disorder (ADHD) and compared those to normal controls. We found significant differences between ADHD participants and controls during all reaction time tasks. Our controls reaction times appear to be normal when compared to research done with recreationally active individuals without ADHD (Mode A: 0.683 seconds, Mode D: 0.55 seconds).[44] Problems with motor coordination, sequencing, working memory, mental computation, planning, anticipation and many others are commonly seen in the ADHD population.[12] While, Mode DC was the only task that showed significant differences between ADHD participants on and off their medication. Both Mode DH and Mode DD have not been consistent due to small sample sizes. It is common for ADHD patients to have slower and more variable RTs than normal controls when off their medication.[21,22] Further there was only significant differences in variability seen in Mode DD.

Mode A:

Mode A allows us to look at an average RT over a one minute period. Significance differences existed between ADHD participants and controls, with controls demonstrating faster reaction times regardless of ADHD medication usage. It appears that participants with ADHD, in general, have slower reaction times. These findings suggest that even with the help of ADHD medication, recreationally active participants with ADHD to not have normalized RTs compared to controls. This finding was not surprising as research that children with ADHD show poor quality of movement when compared to typically developed children and tend to have less precise and stable movement during tracking tasks.[22,46] Theoretically, children with ADHD

should show a significantly positive skew in their reaction time distributions due to poor concentrations.[21,23]

During the examination of ADHD participants and medication use, we found no significant difference in reaction time due to the effect of medication. On average, there was a trend for slower performance in reaction time when comparing ADHD participants "off medication" reaction times to their "on medication" reaction times. This finding match published research that states children with ADHD have slower movement preparation off their medication.[22] With the use of ADHD medication, specifically stimulant medications, the research shows an acceleration of mean RT.[33] When RT is looked at as a dependent variable, medication seemed to make RTs faster. Further, research suggests that medication improves control of inhibition and the executive control of attention.[34] This research supports our findings that ADHD medication should improve RT.

Much of the research in patients with ADHD examining reaction time revolves around reaction time variability (RTV).[23,31,46] [24–27] Reaction time variability is attributed to periodic lapses of attention. These occur randomly and periodically, causing slower responses in ADHD persons.[23,28–30] In the current study, reaction time variability (RTV) did not show significant variability for Mode A. This lack of variability is not consistent with majority of the research on RTV. For Mode A there was no noted decrease in variability when looking at means either (Mode A on $\bar{x}$:0.358, Mode A off $\bar{x}$:0.344). A potential reason why this would not be consistent with the literature could be due to type of ADHD. Kofler et al.[23] performed a meta-analysis and found that ADHD-combined type were significantly more variable when compared to ADHD-inattention and ADHD-hyperactive.[23] There is the possibility the lack of attention did not occur due to the type of ADHD the participant was diagnosed with.

Mode D:

Mode D allows us to examine physical reaction time of a single response, by looking at both visual and motor reaction times. Within testing of Mode D, we found significant differences between ADHD and controls during all tasks (MDD, MDC, MDH). It appears that ADHD participants have slower reaction times then people without ADHD. This is supported in the literature that ADHD children show less precise and less stable movement patterns during purist task.[47] Further, timing of movements of ADHD groups tend to be more variable and slower.[48]

MDC was the only task, during Mode D, which showed a significant difference when comparing ADHD participants on medication to their off medication trials, with participants performing faster on medication. This appears to be consistent with the literature, supporting medication usage improves reaction time and attentiveness. Drug therapy, especially stimulant treatments, are the most common and effective treatment methods for ADHD.[34–38] Simulants prove to be helpful for 75% of the ADHD patients who use them.[49] Once a stimulant medication has been used, there is a rapid and predictable decrease in disruptive symptoms and an increase in attentiveness shown.[32] Stimulant medication improved not only fine motor skills, but reaction times in ADHD participants.[50,51] Although we only found significance in medication effect during MDC, there are several reasons to why this may be the case for MDC and not MDH or MDD.

One study examined the time between stimuli with inter stimulus intervals (ISI) when observing RT. As ISIs become longer, medication exerted a greater effect with RTs becoming slower, less variable and less positively skewed. The medication effect became linearly larger with increasing ISI of only 1sec, 2sec, and 4sec.[21] This could explain why there were differences

seen between each of the Mode D trials. There was an inconsistent stimuli response time ranging from 2-4 seconds for each task and the stimuli being randomly timed and displayed. Some participants had the potential to have gotten stimuli appearing in a shorter time frame causing there to be less differences when comparing medication usages. While other ADHD participants relied heavily on their medication to maintain focus to respond to stimuli, that may have been separated by the 4 second interval. As ISI increased, participants tend to make fewer errors and have slower and more variable reaction times. [21]

Evidence suggests that reaction time speed showed significantly more slowing in non-medicated groups compared to medicated groups as the ISI increased.[21] When delays in stimuli occur the ability to not choose a stimulus may distract the ADHD person and cause them to be preoccupied with a stimulus that is non-task related.[31] Shorter event rates may cause an increase in the activation state of a person, while longer event rates may cause that underactivation.[31] It has been stated that medication effects would become increasingly evident during longer intervals, which could a result of improved distractibility and attention.[21]

Additionally, explanations for the differences seen between medication uses for Mode DC compared to the other tasks in Mode D, may be attributed to task complexity. Research supports that when the movement is complex RT appears to be longer for ADHD patients off their medications compared to controls.[46] There is sufficient evidence to support the idea that ADHD patients tend to have slower reaction time when the movements are complex and they have difficulty with motor timing, when not on medication.[22] This slowing due to task complexity may be an effect of ADHD participants relying more heavily on visual feedback during movement, which results in the slower outcomes.[52]

We would be remised if we did not discuss energy. The cognitive-energetic model of ADHD suggests that, energy levels of the ADHD patients when increased allows their performance to normalized.[53,54] Having an increased energetic level can be increased by both intrinsic and extrinsic factors. Extrinsic factors include making the task more challenging, for example when there is decreased ISI. While an intrinsic example would be the use of a stimulant medication.[21] Epstein, et al.[21] found that both intrinsic and extrinsic manipulations caused ADHD participants to perform better.[21]

Lastly, differences in medication use could play a role in why only MDC showed significance in regards to medication usage. Although Adderall (amphetamines) and Vyvance (lisdexamfetamine) were the most common medications used for our participants, we did not have a minimum or maximum dosage amount. Different dosages as well as type of medication, whether it be slow release or quick release of stimulant could affect the RT results depending on the time of medication intake. The research states that Two of the most common stimulants used for ADHD include methylphenidate and amphetamines, which are said to be equally effective.[34] Methylphenidate has quick effects, and changes in behavior are seen within 20 to 60 minutes after oral consumption. The peak effects of methylphenidate occur around 90 to 180 minutes and the therapeutic effects tend to subside after 4-8 hours.[10] Its half-life is between 2 to 7 hours and is metabolized by the liver.[10] Methylphenidate is said to be preferred over amphetamines due to its slower uptake and clearance.[55] With having these differences seen in peak effects and half-life could truly explain differences seen in RT between participants and medication usage.

In the current study, reaction time variability (RTV) only showed significant variability for Mode DD. With Mode DD you are able to see the decrease in RTV when on medication (Mode DD off $\bar{x}$:0.145, Mode DD on $\bar{x}$:0.082). This decrease in variability due to medication is

consistent within the literature. Research tends to demonstrate large reaction time variability when the participants were off and on medication, where stimulants were associated with large decreases in RTV.[23] Research establishes that medicated individuals had much less positive skewness than non-medicated individuals.[21] This suggests that the ADHD patients on medication are having fewer and less severe lapses in attention due to the medication.[21] Additionally, research shows, medication appears to slow down RT and make RT less variable.[21] Subjects who have an increased positive skew in their distributions tended to have higher mean RT and more variability in their RT as a result.[21]

Limitations:

This study is not without limitations. First, this study has a small sample size of participants with ADHD. The small number of ADHD participants that were on stimulant medication limited the power and reduced the effect sizes seen. This low power had the potential of affecting the significance of some of the results, especially with MDC when comparing the effects of medication of controls to ADHD patients.

Another limitation of this study is the possibility of a practice effect seen with Mode A within the Dynavision. Most of the participants in this study, controls and ADHD participants, performed better their second time coming in for testing. With that being seen one can conclude that the more a participant uses the Dynavision the better they will perform. This may mitigate medication use if strong practice effects exist.

Medication used is easily another limitation for this study. The researcher did ask the for the type of medication on the demographics sheet (Appendix D), but there was no exclusion nor inclusion criteria in terms of type of medication, dosage of medication or time of consumption of

medication. These three factors have the potential to play a significant role in differences seen in this study.

Lastly, we did not obtain the specific ADHD diagnosis or confirm ADHD diagnosis with physician notes. Although not asked, each participant may have had a different form of ADHD, whether that be inattentive type, the hyperactive type or combined type. Pitcher et al.,[56] stated that the ADHD inattentive group showed differences compared to controls, but found no difference between the other subtypes of ADHD.[56] That study also found differences with both ADHD inattentive and ADHD combined, but did not find any differences with the ADHD hyperactive group in regards to impaired motor skills or severe impairments to fine motor skills.[13]

CHAPTER 5

CONCLUSION

In conclusion, we found significant differences between ADHD participants and controls during all test measures, with controls completing tasks faster than ADHD participants. Our findings support the research that ADHD patients have slower and more variable RTs than normal controls.[21,22] ADHD patients have shown cognitive impairments and skills that fall outside of normal ranges. These include executive functions, such as memory, information processing speed and basic motor functions.[57,58] It has been regularly cited that children and adolescents with ADHD commonly have poor coordination, poor balance and poor motor ability.[13–16] Examination of ADHD in children reveal below average fitness and fundamental gross motor skills when compared to normal matched individuals.[15] The findings in this study are one of the first to look at the recreationally active adult population with ADHD and analyze their reaction time compared to normal controls.

It seems as though medication use did not affect reaction times across all tests and only Mode DC may be sensitive to medication use. The use of ADHD medication, specifically stimulant medications, appears to accelerate mean RT and reduce RTV. While our study, it showed there were inconsistencies of medication effects seen within ADHD in this study, which is not consistent with the ADHD population. The majority of research with ADHD shows children have poorer motor skills than typically developed peers, both with fine motor skills as well as gross motor skills.[59] The mechanism by which medication for ADHD persons improves motor skills and motor control is still not clear.[22] Although some children demonstrated improvements on medication, others did not show significance. Moreover, there are still

differences seen in ADHD patients that can vary due to qualities such as type of test, type of ADHD, severity of ADHD, and type of medication.

This research provides evidence that ADHD participants do indeed have slower reaction times compared to controls. Future research should investigate ADHD in Division I college athletes in regards to RT and RTV and how it could affect their ability to participate in sports.

APPENDIX A

Research Questions:

1. Does reaction time differ between ADHD participants off medication compared to controls?
2. Does reaction time differ between ADHD participants on medication compared to controls?
3. Does reaction time differ between ADHD participants on medication verses off medication?

Inclusion Criteria

- **ADHD Participants:**
    - Ages 18-25 years old
    - Have a self-reported ADHD diagnosis
    - Prescribed stimulant medication
    - Must be recreationally active
- **Control Participants:**
    - Ages 18-25 years old
    - Must be recreationally active
    - Must not have a diagnosis of ADHD

Exclusion Criteria

- Musculoskeletal or head injuries within the last 6 months
- Patients prescribed non-stimulant medication
- Mental health comorbidities (anxiety, depression)

- No other prescribed medication for other comorbidities (high blood pressure, narcolepsy, asthma, etc)
- Smoking
- Use of alcohol within 24 hours of testing
- ADHD individuals who consistently take their medication and are unable normally function without the use of medication

Limitations

Limitations for this study are as follows:

- Convenience Sample
- Self-reported ADHD
- Practice Effect of the Dynavision
- Motivation/Effort of participants
- Lack of Randomization
- Sample size

Delimitations

Delimitations for this study are as follows:

- Collegiate aged recreationally active individuals
- A self-reported diagnosis of ADHD
- Variability of prescribed stimulant medication

Assumptions

Assumptions researchers made during this study are as follows:

- Equipment will work properly
- Participants will attend both testing trials

- Participants will put forth their best effort
- Participants will be honest about ADHD
    - Diagnosis
    - Type of medication
    - Time of taking medication

Definitions

The following definitions will be used to assist in clarification for this paper:

- Recreationally active: participating in some form of physical activity for 20 min three times per week.[60]
- Off medication: a day where the participant has not taken their medication within their normal consumption schedule
- Effort: how hard the participant tries during testing trials

APPPENDIX B

LITERATURE REVIEW

Introduction:

Attention Deficit Hyperactivity Disorder (ADHD) is neurodevelopmental/ neurobehavioral disorder defined by chronic and impairing behavior patterns that cause abnormal levels of attention and focus, hyperactivity, impulsivity and disorganization.[1–3,38] Neurodevelopmental disorders are caused by a group of conditions that occur during the early developmental stages of life. These disorders can be characterized by showing deficits in personal, social, academic or occupational functioning.[1] ADHD is the most common neurodevelopmental disorder seen in the childhood population.[3,61] Even though ADHD is one of the most studied childhood neurodevelopmental disorders, it still has had little attention over the past several years.[3]

Pathophysiology:

There is no known cause of ADHD, but there are several hypotheses behind this disorder. The first hypothesis is there is reduced brain function in ADHD individuals, due to visible reduction in functionality and volume of gray and white matter within the brain.[6] This reduction is thought to cause deficits in cognitive processing, as well as, deficits in attention, motor planning, speed of processing responses and multiple other behavioral characteristics that are commonly seen in persons with ADHD.[6]

An alternative hypothesis consists of research showing prefrontal cortex (PFC), caudate and cerebellum discrepancies in ADHD patients. These structures in the brain help with regulating attention, thoughts, emotions, behaviors and actions.[7,8] Having regulation of the previously stated qualities, there is a plausible reason for one to consider that high rates of comorbidities seen in individuals with ADHD, could be due to the brain's regulation process.

Studies have shown that individuals with ADHD have slower PFC maturation[62] and/or reduced activity of the caudate, cerebellum or PFC.[7] This system of the brain is sensitive to it's neurochemical environment and is continuously maintained by the neurotransmitters dopamine and norepinephrine, using multiple receptors.[7,63,64] Cortese et al.[6] and Tripp et al.[65] have shown a lower density of dopamine receptors in the brains of ADHD persons.[6,65] Others researchers have discussed the idea of hyperactive dopamine and/or norepinephrine functioning in ADHD persons.[64] Even with these studies, there is no conclusive evidence suggesting the cause of ADHD. There seems to be a trend that either hyperactivity or underactivity of dopamine and/or norepinephrine receptors as potential causes to ADHD.[34]

Epidemiology:

Attention Deficit Hyperactivity Disorder is among one of the most common neurobehavioral/neurodevelopmental disorders affecting children between the ages 6 to 17 years old.[1,5,66] The prevalence of ADHD ranges from 2% to 18% of the United States population.[3,5,11] This heterogeneous neuropsychiatric disorder affects 8% to 10% of school-aged children.[10,38,67,68] This number has increased with previous studies declaring this disorder affecting 4% to 10%.[3,69] The percentage of children with ADHD continues to increase, with 7.8% of children diagnosed in 2003, 9.5% diagnosed in 2007 and 11.0% diagnosed in 2011.[9] These rates have shown to increase on average about 3% per year from 1997 to 2006, and an average of 5% per year from the years 2003 to 2011.[9]

ADHD in Children:

In 2010 it was approximated that 2.8 to 3.9 million United States children had been diagnosed with ADHD.[23] There is a 2:1 ratio of males to females with ADHD in their childhood years.[1] Males are three times more likely to have ADHD than females in the general

population.[1,2] The annual cost of a child with ADHD was determined to be $14,000 per child.[23,70] Although ADHD is more commonly diagnosed in the younger populations, it can continue to show symptoms into adulthood. [11,71]

ADHD in Adolescents and Adults:

Unlike most psychiatric disorders which are found in adulthood, ADHD is usually first discovered in childhood and can persist into adolescence and adulthood.[38] Since this is usually a childhood disorder, adult ADHD is not well recognized outside of specialty clinics.[72] There is a 1.6:1 ratio males to females with ADHD in adults.[1] Sixty five to eighty percent of children diagnosed with ADHD continue to meet the criteria for adult ADHD, even with the diminishment of symptoms due to maturation.[34] Sixty to eighty percent of adolescents and adults with ADHD continue to show symptoms into their adolescent and adult years.[2,10] Meaning adolescents and adults continue to show functionally impairing symptoms as they continue to age.[23]

It is estimated that 2.5% to 4.5% of adults in the United States have ADHD and 3.4% of adults worldwide.[1,11,73–76] A study that followed ADHD patients, who met the full criteria for persistent ADHD, reported 15% of the children who followed up at age 25 continued to show full ADHD diagnose.[77] This rate of persistence increased when the study included cases that met the DSM-IVs definition of ADHD partial remission, increasing to 65%.[77] In a study done by Karam et al.[78] 69.8% of the participants previously diagnosed with ADHD continued to meet the Diagnostic and Statistical Manual for mental disorders- the 4th edition (DSM-IV) criteria for ADHD.[78]

With age, ADHD symptoms may change. Adolescents may not have difficulty with the hyperactivity aspects, but may show more concerns in regards to risky behaviors and/or time

management problems. Adults with ADHD have trouble with executive functioning such as management of time, prioritization and completion of tasks.[38] There are no known onsets of ADHD in adulthood. It is common for symptoms during the childhood and adolescence years to go unreported, however, this tends to result from compensating efforts that are reduced or unavailable. [79] These symptoms are then recognized later due to adult stresses.[79] There is still controversy on whether adult ADHD is a "real" condition.[80]

ADHD:

ADHD is a behavior disorder that can be defined by chronic and impairing behavioral patterns. These patterns cause abnormal levels of hyperactivity, inattention and/or a combination of both, which can lead to a disoriented lifestyle.[1,2,81,82] ADHD usually results in having impairments with social, academic, occupational functions and hindering family functioning.[1,38] ADHD is usually associated with a lack of planning, lack of restraint, higher rates of danger, perceived lower health and social support and high stress levels when compared to persons without ADHD.[75] ADHD can present in three different subtypes; predominantly inattentive presentation, predominantly hyperactive/impulsive presentation or a combined presentation.[1,3,5]

Types of ADHD:

Hyperactive characteristics present as restlessness, over activity, inability to wait, not staying seated and fidgeting. Impulsivity is portrayed as impatience, reckless job and relationship changes or sensation seeking behaviors.[1,10,73] Inattention presents as procrastination, the ability to not complete tasks, forgetfulness, disorganization and seeming as if not listening.[1,10,73] Males tend to have more prevalence in the predominantly hyperactive or combined subtypes,[2] while females are more likely to show predominantly inattentive subtypes.[1,83] Females with ADHD are also more likely to suffer from eating disorders and

mental impairments when compared to male counterparts.[83] One important aspect of diagnosing a patient with ADHD is the ability to differentiate ADHD from other neurodevelopmental, neurobehavioral as well as other possible disorders.

Comorbidities can make proper diagnosis of ADHD more challenging because of many common symptoms seen in both ADHD and in other disorders.[1,34] Fifty percent of children who are diagnosed with ADHD simultaneously meet the criteria for defiant disorders or conduct disorders. These characteristics can be seen most commonly in people with combined presentation of ADHD, as well as in the predominantly inattentive ADHD population.[1,38] There is a wide range of children with ADHD, ranging from 3% to 75%, who have also been diagnosed with depressive disorders.[84]

ADHD often presents with one or more comorbidities and other psychiatric disorders. Examples of comorbidities include, but are not limited to; disruptive behavior disorders, anxiety disorders, depressive disorders, psychotic disorders, pervasive developmental disorders, substance abuse disorders and learning disorders.[3,5,85] These high rates of comorbidities are reasons it is important for clinicians to have a thorough evaluation of patients who are showing signs of ADHD. If a clinician pays close attention to the differences in quality, severity and onset of characteristics of disorders, it can be easily differentiated between ADHD and other disorders with similar symptoms.[73]

Diagnosis of ADHD:

The proper diagnosis of ADHD is important and consists of a lengthy process not only for the individual being diagnosed, but their family as well. A diagnosis process can be used for certain individuals, such as children, who are unable to undergo a full systematic assessment of intellectual functioning, due to their inability to complete standardized tests because of their

young ages.[1] ADHD has often been diagnosed by pediatricians and/or other primary care providers rather than psychologist or psychiatrists.[3] Trained clinicians primarily use the Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-5) to aid in the diagnosis of ADHD.[1,34] Only 38% of 3,900 physicians surveyed stated using the DSM-5, while 62% of physicians make their diagnosis based solely on their clinical experience and intuition. This shows that physicians and primary care providers tend not to use the DSM-5 properly during their evaluation of ADHD.[3]

The typical diagnosis process for ADHD includes rating scales that the individual must fill out themselves, as well as their parents, teachers and any other caregivers. These are given to assess their internal behaviors to include or exclude comorbidities as well as assess external behaviors such as hyperactivity, impulsivity and inattention.[34,79,86] These scales consist of items describing behavioral aspects of ADHD as well as describing the frequency of these behaviors. These rating scales are then compared to normal developmental aspects to see if a classification of ADHD is being met.[79] The diagnosis depends heavily on the reports from the parents and teachers, as they are able to see the child's behavior in multiple settings on a daily basis for long periods of times.[87]

In the adult diagnosis of ADHD the use of clinical interviews, subjective reporting from patients and others, as well as symptom rating scales are used.[88] To be diagnosed with ADHD the individual must present with six of the diagnostic symptoms for at least six months in one or both of the subtype groups to confirm a diagnosis of ADHD. There must also be obvious functional impairment directly on social, academic and occupational aspects of that individuals life.[1,5,89] There must also be an inconsistency with development levels compared to those of equal age.[1] If a person being evaluated for ADHD is over the age of 17 years, they only need to

meet 5 of the diagnostic symptoms for a total of six months.[1,5,34] However, according to previous diagnostic criteria, an individual must have had observable symptoms before the age of 7.[81] That has recently changed to patients must show observable symptoms before age 12.[1]

ADHD diagnoses should be made by trained clinicians after multiple observational settings as well as after receiving reports form parents, teachers and caregivers or significant others. This method ensures that there are no comorbities disguising as ADHD or acting alongside ADHD.[38,90,91] Neuropsychological tests have shown to be beneficial in aiding with the diagnosis of ADHD in obtaining further information. They measure visual and/or auditory attention and concentration, which the ADHD population shows impairments.[79] These tests usually are performed in areas of little distraction, which could potentially minimize any difficulties that are commonly seen in an individual when they are in a real life setting.[92]

Neuropsychological testing may be beneficial in clarifying impairments in executive function in adults with ADHD, but these tests alone are not yet reliable in the diagnosis of ADHD.[93] Occasionally, computerized tests are used for measuring attention and impulsivity, which can be used alongside clinical evaluations of ADHD. Unfortunately, these computerized measures lack sensitivity and specificity needed for diagnosis.[94] Patients with ADHD are consistently inconsistent with both behavioral tests as well as neurocognitive tests.[23] The final step for proper diagnosis is to have a positive response from treatment measures to confirm diagnosis.[79]

Management of ADHD:

There are a few ways that ADHD can be managed. These treatment methods include drug therapy, behavioral therapy and a combination of both.[34] An early and effective treatment has shown to have better results for the patient. This in turn causes fewer problems as this disorder commonly extends into adulthood.[2] The initial mechanism behind ADHD was thought to be bad parenting, and it was believed that behavioral treatment would be the most beneficial approach to treating patients.[95,96] However, this technique was not a universal resolution for patients.[34]

Behavior management was beneficial in regards to helping adjust to difficult situations such as poor academic performance, peer relationships and disruptive behaviors in school or with the family.[97,98] It has been reported that behavioral treatment along with a low dose of a stimulant drug was shown to be beneficial.[99] Less than 1 in 3 children receive both behavioral therapy and drug therapy for their ADHD.[9] The use of drug therapy has been seen to be more effective than behavioral therapy, due to the realization that this disorder was a neurochemical issue, rather than an effect of poor parenting.[34] Treatment of ADHD symptoms with drug therapy was seen as being superior to behavioral therapy, but there is a positive outcome when both are combined.[100–102]

Drug therapy, especially stimulant treatments, are the most common and effective treatment methods for ADHD.[34–38] The Food and Drug Administration (FDA), has approved multiple drugs used in drug therapy of ADHD. These drugs include stimulants, which are the most popular form of treatment, and nonstimulant treatments. Nonstimulant medications are considered an alternative method of drug therapy if adverse reactions occur with stimulant medication. There are also off label treatments such as tricyclic antidepressants, immediate release alpha 2 agonists and bupropion. These off label treatments are only used if the stimulant

and nonstimulant drugs show no signs of symptoms subsiding.[34] Approximately 56% of people with ADHD are being treated by pharmacological methods, with a majority of those being stimulants.[39]

Simulants are seen to be helpful for 75% of the ADHD patients who use them.[49] Stimulants interact with DAT-1 and norepinephrine transporters which cause inhibition of reuptake of dopamine and norepinephrine.[64] Two of the most common stimulants used for ADHD include methylphenidate and amphetamines, which are said to be equally effective.[34] Methylphenidate has quick effects, and changes in behavior are seen within 20 to 60 minutes after oral consumption. The peak effects of methylphenidate occur around 90 to 180 minutes and the therapeutic effects tend to subside after 4-8 hours.[10] Its half-life is between 2 to 7 hours and is metabolized by the liver.[10] Methylphenidate is said to be preferred over amphetamines due to its slower uptake and clearance, which makes it less likely to cause dependence and physical harm.[55]

There is controversy on the use of amphetamines and methylphenidate due to the fact that they are ranked as the 6th and 12th substances respectively to cause physical harm and the 8th and 13th substances respectively for dependence.[55] In a survey of adolescents and adults, 25% admitted to abusing or altering the use of their stimulant drugs.[34] College students nationwide were surveyed and 4% stated using Ritalin at least once without a prescription in 2006.[103] While, in 2008 5.3% of college students admitted to using stimulants for nonmedical reasons.[104] The use and abuse of stimulant medication has increased, and physicians should be aware of the signs of inappropriate use of ADHD medication, especially among athletes.[79]

There are concerns of the use of stimulant medication in many aspects of life. For children who have received stimulant medication, 75% showed drastic improvements in

behavior, academic performance, cognitive performance and socialization.[40] There are concerns about stimulant medication giving ADHD patients unfair advantages in areas of academics, as well as occupational performance when compared to normal counter partners.[34] With these seen advantages there are also some disadvantages to this medication that should be considered.

Stimulant medication may be the more common drug therapy, but may not be suitable for up to 30% of the ADHD population.[105,106] Stimulant medication is prescribed to over 1 million school aged children.[107] Every patient has a different response to their medication, which can cause physicians to use a trial and error method to determine appropriate dosage. Doses are increased slowly every 1 to 3 weeks from the starting does, which is based off body weight until the proper dose to reduce symptoms is met.[108–110] This method tends to be trial and error and based off clinicians previous experiences. With these stimulant drugs there are also hazardous side effects.

Side effects of stimulant drugs include; insomnia, anorexia, abdominal pain, weight loss, headache, irritability, emotional ability, anxiety, increased blood pressure, dry mouth, nausea, vomiting, diarrhea, and tics.[34,111,112] Adverse effects can last up to 24 hours initially, but the severity of these effects tend to diminish after the first two weeks of consumption.[10] Contraindications for the use of stimulant medication include persons with hypertension, glaucoma, hyperthyroidism, symptomatic cardiovascular disease, structural heart disease, psychosis, stimulant hypersensitivity, history of drug dependence, and associated use of monoamine oxidase (MAO) inhibitor.[113] For patients who do not see improvement of symptoms with stimulant medication there are multiple drug therapy options available.

The second option of medication for ADHD individuals is nonstimulant medication. This is usually given when stimulant drugs are nonresponsive and/or when the adverse side

effects worsen symptoms or cause more concerns, as well as based on family history and family preference on medication.[34] Nonstimulants increase the availability of both norepinephrine and dopamine in the synapse of the PFC, which is thought to improve the function of the PFC in persons with ADHD.[114,115] Nonstimulant medication was approve by the FDA for the treatment of ADHD in 2003[34,38] and can last up to 24 hours.[38] Unfortunately, due to lack of initial effects, some nonstimulants medication require 4 to 6 weeks to show full effect of medication.[116] Like stimulants and any other oral medication, nonstimulants also have adverse side effects. These side effects include decreased appetite, nausea, vomiting, fatigue, insomnia, abdominal pain, increased sweating, dry mouth, hepatotoxicity, constipation, somnolence, urinary retention, dysuria, erectile dysfunction and dysmenorrhea.[34,79] With many treatment options for ADHD, inadequate treatment is common and continues to be an issue in the ADHD population.[117] Treatment guidelines are not well established causing clinicians to rely heavily on clinical experiences, as well as the patient's response to medication and parents observations upon starting medication.[34]

ADHD in Athletes:

The adult ADHD controversy is further complicated with the debate regarding ADHD in athletes. ADHD in athletes has been shown to cause cognitive impairment which has been seen to affect motor coordination along with sequencing, anticipation, and planning.[10] Other common traits seen in athletes with ADHD include poor attention span, difficulty initiating or completing tasks, especially when they are not engaged, difficulty waiting, increased risky behavior, inability to manage time, and trouble with organization skills.[38]

Speculations exist regarding the effects of ADHD medication, especially stimulants, on an athlete's ability to participate in sports.[38] Some athletes have started taking their medication

with the mindset that they will have improved sports performance while on their stimulant medication. Other athletes may stop taking their medication in hopes that their unfocused mind and unpredictable qualities will improve their performance.[41] Side effects of stimulant medication that can negatively affect the athlete's performance include suppressed appetite, causing the athlete not to gain weight if needed, as well as delayed growth.[112]

Medication Restrictions for Athletes with ADHD:

Knowledge of medication is important in the collegiate setting due to strict National Collegiate Athletic Association (NCAA) regulations. In the collegiate setting, if an athlete is prescribed a stimulant drug for the treatment of ADHD, the NCAA requires certain documentation. This documentation must include, at a minimum, a description of the evaluation process, including assessment tools used and the procedures performed to arrive at the diagnosis. A statement of the exact diagnosis, history of ADHD treatment, a statement from a physician that non-banned alternatives were considered, which include non-stimulants and counseling, as well as documented follow ups monitoring vitals.[38,79,88] The athlete must also have annual evaluations and report their condition to the medical staff and athletics department immediately.[38,79,88] Stimulants used by athletes are banned during competition in all World Anti-Doping Agency (WADA)[38,79], United States Anti-Doping Agency (USADA),[38] and International Olympic Committee (IOC) events.[79] It is necessary for physicians who work with athletes at all levels to know and understand rules and regulations for medications athletes are taking.

General Reaction Time:

When looking at fine and gross motor skills, an important aspect to consider is reaction time. Reaction time has been defined as the time it takes to initiate a response after a sensory stimulus has been brought about.[17] Simple reaction is a task in which an individual performs the same response to a single stimulus every trial.[18–20] Complex reaction involves more than one stimuli and/or response across different trials.[18]

An accepted number for mean simple reaction time in college aged people has been reported as approximately 190ms for light stimuli and 160ms for sound stimuli.[20,118] Visual stimuli takes about 20-40ms to reach the brain,[119] causing visual reaction times to range from 180-200ms.[20,118] The fastest reaction times arise when a stimulus is seen by the cones of the eye, meaning the person was looking right at the stimuli. When the stimulus was detected by the rods, or around the edge of the eye, the reaction was seen to be slower.[120] Ando et al.[121] found that, when practiced, reaction time to a visual stimuli in the central vision area is shortened, as well as with practice the reaction time to a stimulus in peripheral vision is also shortened.[121]

Comparing ADHD to Non-ADHD:

There are noticeable differences between people with and without ADHD. People with ADHD have shown cognitive impairments and skills that fall outside of normal ranges. These include executive functions, such as memory, information processing speed and basic motor functions.[57,58] Executive function refers to a set of cognitive processes that enable a person to deal with uniqueness, select strategies to solve problems, inhibit inappropriate responses, monitor performance and adjust behaviors to achieve goals.[73] Problems with motor coordination, sequencing, working memory, mental computation, planning, anticipation and many others are commonly seen.[12]

It has been regularly cited that children and adolescents with ADHD commonly have poor coordination, poor balance and poor motor ability.[13–16] One of the major problems in adulthood ADHD is inattention and executive dysfunction,[1,73,122,123] issues with time management, prioritization, and task completion.[38] These traits are usually associated with adult ADHD due to the higher cognitive demands.[122] Common traits seen in athletes with ADHD who don't receive medication are poor attention spans, difficulty initiating tasks that are boring and not engaging, too much attention to a novel situation, difficulty waiting one's turn, increased risky behaviors, inability to manage own time, difficulties with unstructured time and lack of organization skills.[79] There is little research on the physical fitness and gross motor skills in children with ADHD.[15]

Movement Skills in ADHD:

Movement skills are necessary in a person's ability to perform sport specific activities, as well as have functional involvement in physical activity.[124] Research has suggested that children with ADHD may be at a higher risk for movement skill difficulties.[16] Patients with ADHD may be at risk for developmental delays in fundamental movement skill performances compared to peers.[16] Children with ADHD have demonstrated not performing well with movement related activities, but this has still not fully been proven.[125] When looking at children with ADHD in terms of fitness and fundamental gross motor skills, they tended to be below average when compared to normal matched individuals.[15] It is observed that older children have better fundamental movement skills than younger children.[16] With deficits in movement being seen in children with ADHD, within activities of daily living, this could cause concerns about that person's ability to play sports.

Reaction time Variability in ADHD:

Individuals with ADHD show increased reaction time variability (RTV) across a large range of tasks including measuring reaction time motor speed, choice decision, vigilance, behavioral inhibition, cognitive interference, working memory, visual saccade, and visual discrimination.[24–27] Reaction time variability is attributed to periodic lapses of attention. These occur randomly and periodically, causing slower responses in ADHD persons.[23,28–30] Reaction time variability can be described as an inconsistency in a person's responding speed, which is measured in seconds or milliseconds.[26] Another term commonly used in research regarding reaction time variability in ADHD patients is intra-individual variability.

Intra-individual variability refers to the moment-to-moment (within a subject) fluctuations in behaviors and task performances occurring over shorter periods of time rather than hours or days.[31,126] Long reaction times are seen to be a part of similar cognitive process that surround omission errors.[31] Omission errors occur when the participant does not respond to a target stimuli.[127] This inability to respond could be due to the lapse in attention requiring longer reaction times.[31] Children with ADHD experience impaired senses of time, implying they may get caught up in the moment.[87] When performing computerized tests, errors of inattention (omission errors), an inconsistency of reaction time, are seen to occur regularly with ADHD-inattentive type.[38] Longer reaction times have been noticed in children before an omission error occurs, as well as slowing motions after an omission error occurs.[31] RTV appears to be characterized as a single factor in children with ADHD, which could suggest a stable characteristic in ADHD patients despite large differences in task demands.[26]

Research in the past 8 years has shown reaction time variability could be a feature of ADHD patients.[23] Reaction time distributions tend to be positively skewed especially for

individuals with ADHD resulting in abnormally slower responses.[23] Willcutt et al.[27] has shown a moderate to large magnitude d=0.71 in ADHD patients in regards to intra-individual variability compared to variability of normally developing children.[27] Kofler et al.[23] performed a meta-analysis and found that ADHD-combined type were significantly more variable when compared to ADHD-inattention and ADHD-hyperactive.[23] Harvey et al.[16] used the TGMD-2 to look at 12 movement skills. The TGMD-2 is commonly used in physical education departments to test and assess 6 locomotive skills (run, gallop, hop, leap, horizontal jump and slide) as well as 6 objective control skills (striking a stationary ball, stationary dribble, catch, kick, overhand throw and underhand roll). It was noticed that children with ADHD scored worse than peers without ADHD in both the placebo and medication trials.[16]

Bedard et al.[123] looked at the ability to inhibit inappropriate motor responses and to ignore irrelevant stimuli in the ADHD population.[123] This study indicated that ADHD children had a greater proportion of invalid trials when compared to normally developed counter partners.[123] Children with ADHD showed a larger proportion of invalid trials when compared to that of non ADHD participants. Using 5 computer tasks, ADHD participants were less accurate ($p=0.004$), more variable ($p=0.01$) and slower ($p=0.004$).[123] Reaction time variability may normalize after the effects of taking stimulant medication are established.[126,128,129]

Once a stimulant medication has been used, there is a rapid and predictable decrease in disruptive symptoms and an increase in attentiveness shown.[32] Benefits of stimulants include attention and concentration improvements as well as fine motor coordination and balance.[10] Stimulant medications may enhance task efficiency rather than achievement outcomes.[16] Methylphenidates/stimulants were associated with large decreases in RTV, while nonstimulant medication treatment did not change RTV significantly in ADHD individuals.[23] Since no

significant changes were found in the nonstimulant category they were viewed as ineffective for these patients.[23] A study demonstrated that patients with ADHD had significantly improved or normalized RTV when medicated with their medication.[23]

Stimulant medications has demonstrated a large magnitude effect on RTV for individuals with ADHD, indicating that about 45% of individuals scored outside of their pretreatment range after taking a stimulant medication. Harvey et al.[16] showed no significance between or within the effects of the medication on purely movement skills performed in boys with ADHD.[16] Although the data states mixed outcomes on the effects of stimulant medication on participants with ADHD, it is thought that athletes with ADHD may be perceived as having an unfair advantage in competition.[16]

There are certainly concerns for athletes who are on stimulant medication that team physicians and sports medicine staffs should be aware. First, stimulant medication has the potential for abuse by ADHD patients.[79] ADHD patients who consume stimulant medication have increased core temperatures and may have a higher risk for heat illness.[79] Methylphenidate can elevate the heart rate, initially by 11 beats per minute for patients who are new to the stimulant and elevate 4 beats per minute for individuals who have been on the medication for an extended period of time.[130] It is also common for stimulant medications to increase blood pressure in athletes.[131,132] In the adult population stimulants have shown to increase blood pressure by 4mmHg.[73] With these commonly seen issues the American Heart Association suggests that physicians continuously monitor athletes blood pressure and heart rates while the athletes continue to take stimulant medication.[79] While there are some disadvantages of adult ADHD, there are recorded benefits for stimulant medication.

Fine motor coordination and balance are shown to improve after the administration of methylphenidate.[13,50] Stimulant medication improved not only fine motor skills, but reaction times in ADHD participants.[50,51] The improvements seen in concentration and attention are considered beneficial in sports.[133] Chandler et al.[134]noticed that amphetamines were able to significantly improve acceleration of ADHD individuals.[134] When observing students in college without ADHD, no increases in strength, power, nor speed were seen, but improvements in acceleration with the use of amphetamines in non-ADHD individuals was observed.[134] Methylphenidate at the dose of 0.3 mg/kg and 0.6 mg/kg showed to have a positive effect on attention span during games.[16,38] Five out of nine people previously diagnosed with ADHD, who were taking Ritalin, showed improved skills while on medication.[16] A study found that 77% of its subjects performed better on amphetamines, while 59% stated having only subjective helpfulness of the drug.[38] Subjective enhancements in performance may include sense of euphoria, improved concentration and increased aggression along with a decrease in reporting pain.[135] Methylphenidate, modafinil and bupropion have been seen to have the ability to mask symptoms of fatigue especially in areas of warm climate.[136] As a general statement, athletic individuals who are given a stimulant medication noticed an improvement in sports performance. They did see effects vary for each individual and the nature of the sport they participated in.[10] Athletes who choose stimulant treatment may be able to focus better on a task and be more aware of positions and time in sports.[38]

Reaction time assessment tools:

The Ruler Drop test (drop test) is a clinical tool that measures reaction time and movement time.[137] The Ruler Drop test is a simple clinical standardized visuomotor reaction time test made of an 83cm long measuring stick covered with high friction tape, marked in 0.5

cm increments, which is then embedded into a hockey puck.[137–139] Participants are seated with their dominant forearm resting on the table and the hand extending off the edge of the table. The administrator of the exam suspends the drop stick so that the puck is in the space between the open hand and not touching any part of the hand. The instructor then releases the stick within a 2-5 second window; and then the participant is instructed to catch the device as quickly as possible. The placement of the hand on the stick after catching it is then used to measure the reaction time. When the post injury reaction time is slower than the baseline reaction test, it is presumed to be an abnormal test.[18,137,139]

The drop test is currently used in concussion assessment for reaction time. The drop test has been recognized in the literature to have a sensitivity of 75% and a specificity of 68% in regards to assessing sports related concussions in athletes, with a confidence level of 65%.[18,137] Eckner et al.[18] reported inter-rater reliabilities for simple reaction time latency measures clinically using the drop test to be 0.74.[18] Latency was described as the time interval between the start of the device accelerating to the start of the device decelerating, the difference between these two numbers are used to find reaction time using this method.[18] Intraclass correlation coefficient (ICC) is used to determine ideal and preferred clinical decision making in regards to techniques that should be used.[139] The ICC rates for simple reaction time range from 0.608[139] to 0.76.[18]

Age has been shown to be a contributing factor to the reliability of simple clinical reaction time (RTclin). ICC for high school to college range from 0.645[140] and 0.68.[139] Age differences have suggested that there is a positive correlation between simple RTclin and age, with the drop test presenting faster reaction times in the collegiate setting.[139] A practice effect was seen in healthy individuals as their reaction times improved after repeating the tasks.[137] It

was thought that the practice effect averaged an improvement of 2.4ms per trial, but was not significant.[138]

Reaction time has shown to steadily plateau after the first trial, this information should encourage clinicians to allow for at least one practice session before the start of baseline or data collection.[137] Unfortunately, there is no known research on the drop test in individuals with ADHD, without a previous history of a head injury.

Another useful tool that can be used to assess and measure reaction time is the Dynavision D2 Visuomotor training device.[44] In an athletic population the Dynavision can be used to improve reaction time, peripheral visual awareness and decision making under stress.[141] The Dynavision has a training surface that consists of small buttons that illuminate, which form a pattern of five rings around each other. As the lights illuminate the participant is to hit the illuminated button. Once it has correctly been selected a beep will signal a successful hit, then the light will move to another random location on the board and that will continue till the end of the test. The device records the total number of hits during the various conditions and are recorded.[43] There are mixed reports of ICC ranges, with studies ICC's ranging from 0.88 to 0.97[43] to 0.73 to 0.84.[44]

There are different settings that can be used with the Dynavision. Mode A, which is one of the more commonly used programs, begins with a 5 second countdown to start the trial. The board then lights up and the participant is supposed to strike the stimulus. Once the light is hit it randomly moves to another section of the board. This continues for 60 seconds, the participant is encouraged to hit as many of the lights has possible with both hands in the allotted amount of time.[44] This showed significance between trial 1 and trial 2 ($p=0.001$).[44] There is a notable learning effect seen in the Mode A technique.[44] Some literature has stated that the Dynavision

does not show a practice effect after three trials.[43,44](48, 50, 51,59) Dynavision showed to have a strong visual reaction time ICC 0.84 and a moderate motor reaction time reliability ICC of 0.63.[44]

Another setting that can be used is Mode D. During this setting the participant holds an illuminated home button with their dominant hand to start the trial. A button in a different section from any of the four locations will light up adjacent to the home button on the same horizontal plane, in a circular pattern, as well as a direct stimuli. Once the participant recognizes the stimuli they leave the home button, then hit the new button that is illuminated. The participant is then required to return back to the home button to proceed with the next trial.[44] The Mode D setting has the ability to measures a participant's visual and motor reaction time.

Visual reaction time for the CRT showed strong reliability having an ICC ranging from 0.73-0.84. [44,142] The motor reaction time had a moderate reliability, having an ICC of 0.63.[44] There were no significant differences between the consecutive sessions when using this test program, indicating there was no learning curve present. This absence of a learning curve could be due to lack of task complexity with this program.[42]

A third program that can be used is the Simple Visual Reaction Test (SRVT). This test requires the participant to hold down one button with their dominant hand and then must hit another key that is 30cm away when a new light occurs as quickly as possible. This test program allows the researcher to simultaneously look at visual reaction time and movement time. [43] There are no known validity or reliability data available for the SVRT setting.

One study looked at lingering deficits following a concussion by assessing visual motor skills using the SVRT Dynavision setting.[143] When that study compared controls to concussed individuals no interaction was found between session or group for either reaction time or

movement time.[143] In this study reaction time was considered the amount of time required for the central nervous system (CNS) to perceive the stimulus and then decide upon and initiate a motor response.[143–145] This study found improvement in reaction time for both groups, which could indicate an increased speed in the CNS planning.[144]

Testing Concerns:

An important concept to take into consideration with ADHD individuals, especially with testing, is their interest and motivation. People with ADHD often have difficulty with initiation or completion of tasks and activities when they find them boring or unengaging.[38] If an ADHD individual finds an activity to be more interesting it is more likely they will perform that task more efficiently.[38] Motivation may potentially play a big role in the skill difficulties experienced by children with ADHD.[16] That is why it is important for a child, especially an athletic child with ADHD, to want to participate in sports that they are interested in and motivated to do, so they do not continue to be at a higher risk for movement issues and inattention.

With testing, another important concept to consider is effort. When testing participants, it is sometimes unclear to the examiner whether maximum effort is being performed during baseline testing.[146] In the past, effort has sometimes been estimated by examiners based on subjective clinical impressions.[147] Poor effort can be associated with impaired test performance showing lower than normal ranges when compared to people with symptoms and organic disorders.[146]

When dealing with medical disabilities examiners need to be aware that test scores may be invalid due to sub-optimal effort.[147] Hunt et. al[146] came to the conclusion that one out of every ten athletes showed poor effort during baseline testing.[146] Green et al.[147] found in his study that effort explained 53% of the variance in neuropsychological test data.[147] Significant

differences are seen between athletes with poor effort and adequate effort with neuropsychological testing.[146] Participants who showed poor effort performed worse on tests measuring information processing, memory, attention/concentration, learning and gross motor speed when compared to an adequate effort group.[146] These traits could be of concern for the ADHD population and their effort towards testing.

Conclusion

In conclusion, attention deficit hyperactivity disorder is a neurodevelopmental/ neurobehavioral disorder that is very prevalent.[1,5,66] ADHD in athletes has been shown to cause cognitive impairment which can affect motor coordination along with sequencing, anticipation and planning.[10] Other common traits seen in athletes with ADHD include; poor attention span, difficulty initiating or completing tasks, especially when they are not engaged, difficulty waiting, increased risky behavior, inability to manage time, and trouble with organization skills.[38] The common symptoms seen in patients with ADHD will likely affect their sports performances. Altered sport performance in athletes with ADHD can be due to variability in reaction time. The ability to react while concurrently processing and integrating visual cues in an environment that is continuously changing are key components to being successful in sports.[44] With studies demonstrating lack of fitness and fundamental gross motor skills,[15] it is understood that persons with ADHD may not perform to the same levels of their normally developed peers. Unfortunately, there is little research on the physical fitness and gross motor skills in the athletic population of persons with ADHD.[15]

Stimulant treatments are the most common and effective treatment methods for people diagnosed with ADHD.[34–38] Stimulant medication has shown to help improve sports

performance.[10] With this seen increased performance, ADHD medication continues to be a topic of controversy.

There is still a need for assessments of movement skills of athletes with and without ADHD, as well as discover the effects of stimulant medication on overall fundamental movement.[16] With little research done in this area, the purpose of this study was to determine the effects of stimulant medication on reaction time, in recreationally active individuals with and without self-reported Attention Deficit Hyperactivity Disorder (ADHD).

APPENDIX C

IRB DOCUMENTS

GEORGIA SOUTHERN UNIVERSITY INSTITUTIONAL REVIEW BOARD

PROPOSAL NARRATIVE

Personnel:
The research team includes: Nichole LaFortune, ATC-Graduate Student/Primary Investigator, Dr. Tamerah Hunt, PhD – Georgia Southern Faculty Member/Co-Investigator (CHAIR) has experience working with the ADHD population with concussion research, Dr. George Shaver, Psy. D-– Georgia Southern Faculty Member/Co-Investigator has experience working directly with learning disorders such as ADHD and Dr. Barry Munkasey, PhD– Georgia Southern Faculty Member/Co-Investigator has experience working in with biomechanical devices such as the Dynavision, which will be used in this study.

Purpose:
The purpose of this study was to determine the effects of stimulant medication on reaction time, in recreationally active individuals with and without self-reported Attention Deficit Hyperactivity Disorder (ADHD).
Research questions: 1) Does reaction time differ between ADHD participants off medication compared to controls? 2) Does reaction time differ between ADHD participants on medication compared to controls? 3) Does reaction time differ between ADHD participants on medication verses off medication? **Hypotheses:** 1) ADHD participants off their medication will have slower reaction times compared to that of controls. 2) ADHD participants on their medication will have comparable or better reaction times compared to that of controls. 3) ADHD participants on their medication will have better reaction times than when they are off their medication.

Literature Review.

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental/ neurobehavioral disorder defined by chronic and impaired behavior patterns that cause abnormal levels of attention and focus, hyperactivity, impulsivity, and disorganization.[1–4] There continues to be no known cause of ADHD, there are several hypotheses addressing the physiological aspects of this disorder. These hypotheses range from reduced volume and functionality of gray and white matter in the brain[6] to reduced function of the prefrontal cortex (PFC), caudate and cerebellum in ADHD patients.[7,8]

The ADHD population warrants focus as the rates of diagnosis increase every year. In 2003, 7.8% of children in the U.S. were diagnosed with ADHD, then in 2007, 9.5% of children were diagnosed, and in 2011, 11.0% were diagnosed.[9] The diagnosis rates have increased on average about 3% per year from the years 1997 to 2006 and an average of 5% per year from the years 2003 to 2011.[9] Unlike most psychiatric disorders that are discovered in adulthood, ADHD is first diagnosed as a child and can persist into adolescences and adulthood.[4] As high as 60% to 80% of ADHD individuals continue to show symptoms into their adolescent and adult years.[2,10]

It is estimated that 2.5% to 4.5% of adults in the United States have ADHD and 3.4% of adults worldwide.[1,11] With high rates of ADHD people in the population it is important to understand the differences between people with ADHD and people without ADHD.

There are noticeable differences between people with ADHD and without ADHD and an important difference appears in motor performance.[12] It has been regularly cited that children and adolescents with ADHD commonly have poor coordination, poor balance, and poor motor ability.[13–16] These components of motor performance and coordination that are commonly seen as worse in the ADHD population are necessary components within participating in physical activity. Unfortunately, there is little research in the physically active population with ADHD in regards to physical fitness and gross motor skills in the adult population.[15]

Movement skills are necessary in a person's ability to perform physical activities well, including the ability to functionally move during sport activities.[124] Research has suggested that children with ADHD may be at a higher risk for movement skill difficulties.[16] When looking at children with ADHD in terms of fitness and fundamental gross motor skills, they tended to be below average when compared to normal matched individuals.[15] With deficits seen in children with ADHD regarding movement patterns, it can be assumed that these children who progress to have ADHD as adults who are physically active, could demonstrate these deficits in their ability to participate in sport and physical activities.

Potential movement deficits in physically active people with ADHD can be deduced that reaction time would be affected. Reaction time can be defined as the time it takes to initiate a response after a sensory stimulus has been brought about.[17] Individuals with ADHD show increased reaction time variability (RTV) across a large range of tasks including measuring reaction time motor speed, choice decision, vigilance, behavioral inhibition, cognitive interference, working memory, visual saccade and visual discrimination.[24–27]

RTV can be described as an inconsistency in a person's responding speed, which is measured in seconds or milliseconds.[24–27] RTV is attributed to periodic lapses of attention, these occur randomly and periodically, causing slower responses in ADHD persons.[23,28–30] When performing computerized tests, errors of inattention (omission errors), an inconsistency of reaction time, are seen to occur regularly in people with ADHD especially ADHD-inattentive type .[38] With the use of stimulant medication, some of these deficits have shown improvements.

ADHD is a very controversial topic, especially in regards to people who participate in physical activity. People with ADHD have shown to have cognitive impairments. [10] These impairments can affect motor coordination, sequencing, anticipation, and planning.[10] The predisposing disadvantages seen in the ADHD population can affect a person's everyday life. It is just as likely to have an effect the performance levels of physically active individuals during physical activity. Specifically, athletes with ADHD has become a major controversial topic due to the fact that there are speculations in regards to the unknown effects of ADHD medication, especially stimulant medication on a person's ability to participate in sports or physical activity.[4]

Drug therapy, especially stimulant treatments, are the most common and effective treatment and management of ADHD.[34–38] Approximately 56% of people with ADHD are being treated by pharmacological methods, specifically stimulant medication.[39] Each of the medication

has different peak effects, half-life, and patient reactions. There are concerns about stimulant medication, and their advantages for ADHD patients compared to non ADHD population.[34]

One study showed that when prescribed a stimulant medication, there was a 75% improvement in behavior, academic performance, cognitive performance and socialization seen.[40] Some who take stimulant medication have admitted to having a mindset that the medication will help improve their performance with cognition and physicality.[41] The use and abuse of stimulant medication has increased and physicians should be aware of the signs of inappropriate use of ADHD medication, especially among athletes.[79]

Once a stimulant medication has been used, there is a rapid and predictable decrease in disruptive symptoms and an increase in attentiveness shown.[32] Benefits of stimulants include attention and concentration improvements, as well as fine motor coordination and balance improvements.[10] Stimulant medications may have the ability to enhance task efficiency.[16] Stimulants have been associated with large decreases in RTV, showing that patients with ADHD significantly improve or normalized RTV. [23] Although there are mixed sources stating the effects of the medication, some elite athletes with ADHD are perceived as having an unfair advantage in competition.[16] This perceived idea leads to the topic of do stimulant medications give people with ADHD an advantage in performing physical activities.

There is still a need for assessments of movement skills of physically active individuals with and without ADHD as well as the effects of stimulant medication on fundamental movement.[16] The purpose of this study was to determine the effects of stimulant medication on reaction time, in recreationally active individuals with and without self-reported Attention Deficit Hyperactivity Disorder (ADHD).

Outcome. The results of this study will show no immediate benefits for the participants. These results may show the differences in reaction time in the ADHD population while on and off their medication. These outcomes will provide an initial understanding of the effects of commonly used medication used in this population. Further, these results can provide an initial understanding of how ADHD medications may influence reaction time in commonly utilized concussion assessment tool for athletes.

Describe your subjects: Participants will be taken from a convenience sample of recreationally active college students. These participants will be divided into two groups; a control group and a group of self-reported diagnosis of Attention Deficit Hyperactivity Disorder (ADHD). We expect to have a total of 34 participants, 21 controls and 13 self-reported ADHD patients. Inclusion criteria for self-reported ADHD participants: must be between the ages 18-25 years old, males and females who have a self-reported ADHD diagnosis with prescribed stimulant medication and must be recreationally active. The inclusion criteria for the control group: must be between the ages of 18-25 years old, must be recreationally active and must not have a diagnosis of ADHD. Recreationally active is being defined as participating in some form of physical activity for 20 min three times per week.[60] The exclusion criteria for both groups includes: no musculoskeletal or head injury in the last 6 months, patients with prescribed non-stimulant medication, mental health comorbidities, such as anxiety or depression, no other

prescribed medications for comorbidities, must not smoke, no use of alcohol or within 24 hours of testing, and individuals that continuously and regularly take their medication.

Recruitment and Incentives: The participants in this study will do so voluntarily. A paper flyer will be used for participant recruitment. The flyer will be posted in the university's Recreation Activity Center building as well as in the Hollis building. An incentive will be used to help with recruitment. All participants who complete both trials will have their ID numbers placed in a drawing for one $50 Visa gift card.

Research Procedures and Timeline:
Following IRB approval, flyers will be hung Hanner, Hollis, the SDRC, and the student health center. Prior to participant enrollment, ADHD participants will be contacted by the researcher to discuss their normal medication regiment. These normal medicine regiments will be used to determine when scheduling the off medication test session will be completed. Participants will be provided with an informed consent form as well as a demographics sheet prior to testing. For both groups, each person will be assigned an ID number for confidentiality purposes. Only the researcher will have access to the decoding of the ID numbers. The key to the ID numbers will be locked on a password protected computer. Each individual will come into either the biomechanics lab or the RAC and perform two Dynavision testing programs.

The participants will arrive during their specified test date and time to complete tests Mode A and Mode D. This testing will last approximately 20 minutes per test session, requiring two separate test sessions. A follow-up appointment for retesting will be made within the next 48-72 hours. Once all of the data is collected the information will be input into IBM SPSS Statistics 23 software (SPSS Inc, Chicago, IL).

Data Analysis:

This is a prospective pre-post study. The independent variables for this study are the groups (ADHD and Controls) and the testing session (on medication verses off medication). The dependent variables are reaction time outcomes of the individual tests as well as reaction time variability. Statistical analysis will be calculated using IBM SPSS Statistics 23 software (SPSS Inc, Chicago, IL). Statistical assumptions that are accounted for are sphericity, independency of cases, normality, and variance of equality or homogeneity. This study will use a 2 (group) x 2(time) mixed model repeated measures analysis of variance (ANOVA). A paired-sample t-test was run do compare ADHD participants on medication to off medication. This test will look at reaction time of the ADHD population on their medication while off their medication and then compare that to controls. The alpha level will be set a priori at 0.05. The effect size will be calculated using the partial eta squared. The researcher will also manually calculate the reaction time variability (RTV) of the physical reaction time, during Mode D and use the average reaction time over the 3 practice trials and 5 test trials of Mode A. Prior to calculations the researcher will examine normality, outliers and assumptions.

Special Conditions:

Risk: The participants may be at risk of experiencing discomfort in identifying as having ADHD. There may be a negative stigma associated with the diagnosis of ADHD. However, this risk will be mitigated by utilizing ID codes as well as password protected computer for data storage.

Research involving minors: This research study does not involve minors.

Deception. This study does not involve deception.

Medical procedures. This study does not involve medical procedures.

Cover page checklist.
Informed consent was checked on the cover page and has been described in the procedures section of the narrative.

Reminder: No research can be undertaken until your proposal h

INFORMED CONSENT TO ACT AS A SUBJECT IN AN EXPERIMENTAL STUDY

Title of Project: Effects of Stimulant Medication on Reaction Time in Recreationally Active Individuals with Attention Deficit Hyperactivity Disorder

Investigator's Name: Nichole LaFortune, ATC Phone: (804)-381-9767

Participant's Name: _____ Date:_____

Data Collection Location: Hanner Biomechanics Lab, Georgia Southern University

1. My name is Nichole LaFortune and I am an Athletic Training Graduate Assistant at Georgia Southern University. I am doing this research as a requirement to complete my Master's program at Georgia Southern University.

2. The purpose of this study was to determine the effects of stimulant medication on reaction time, in recreationally active individuals with and without self-reported Attention Deficit Hyperactivity Disorder (ADHD).

3. Participants in this study with be divided into two groups, the control group and the self-reported ADHD group. Each participant will be assigned an ID number for confidentiality purposes. Participants will be provided with a consent form as well as a demographics sheet prior to testing. Each individual will come into the biomechanics lab and perform two Dynavision testing programs. Participants will perform the Choice Reaction Test (CRT) also known as Mode D as well as the Simple Visual Reaction Test (SVRT) also referred to as Mode A. They will also answer a post-test effort scale after the completion of their testing. A follow-up appointment for retesting will be made within the next 48-72 hours. Participants will be expected to complete two sessions that will last approximately 20 minutes each.

4. There is minimal risk involved in the study. The participants may be at risk of experiencing discomfort in identifying as having ADHD. There may be a negative stigma associated with the diagnosis of ADHD. However, this risk will be mitigated by utilizing ID codes as well as password protected computer for data storage. If at any time, the participant feels uncomfortable or wish to withdraw from the study they may do so. Additional materials can be provided to the participants with information to seek counseling if necessary.

5. There are no direct benefits to you as the participant. There may be benefits regarding future research, care and outcome of future athletes with ADHD. These benefits may include understanding the impact of commonly prescribed medication on concussion assessment tools. This research could also lead to additional research on ADHD athletes in sports and how medication affect their performance.

6. The duration of the study will be approximately 20 minutes per session for two sessions with the completion of all testing taking approximately 40 minutes.

7. You will not be identified by name in the data set or in any of the reports using information obtained from this study. Your confidentiality as a participant in this study will remain secure. An ID number will be given to you during this study for confidentiality purposes. Only the researcher will have access to the decoding of the ID numbers. Subsequent uses of records and data will be subject to standard data use policies which protect the anonymity of individuals and institutions. All information obtained will be stored on a secure computer that is password protected. After the data is collected and analyzed it will be kept in a secure location for a minimum of three years following the completion of the study.

8. You have the right to ask questions and have those questions answered. If you have questions about the study, please contact the researcher named above or the researcher's faculty advisor, whose contact information is located at the end of the informed consent. For questions concerning your rights as a research participant, contact Georgia Southern University Office of Research Services and Sponsored Programs at 912-478-0843.

9. You will not receive any form of compensation for participation in this study. There will be a $50 gift card that your ID number will be placed into a drawing for the chance to win the gift card once the study is complete.

10. You do not have to participate in this study if you do not want to. Participation in this study is completely voluntary. Even if you begin the testing and wish to withdraw you may do so at any point during the study.

11. There are no penalties for removing yourself from the study or denying participation in the study.

12. All information will be treated confidentially. There is one exception to confidentiality that we need to make you aware of. In certain research studies, it is our ethical responsibility to report situations of child or elder abuse, child or elder neglect, or any life-threatening situation to appropriate authorities. However, we are not seeking this type of information in our study nor will you be asked questions about these issues.

13. You must be 18 years of age or older to consent to participate in this research study. If you consent to participate in this research study and to the terms above, please sign your name and indicate the date below.

You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number H_17089.

Title of Project: The Effect of Stimulant Medication on Reaction Time in Recreationally Active Individuals with ADHD
Principal Investigator:

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_____ _____
Participant Signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

_____ _____
Investigator Signature Date

APPENDIX D

ID Number: _____

Demographic Sheet

1. What is your gender?
    a. Male
    b. Female
2. How old are you?

    _____

    _____
3. How tall are you?

    _____

    _____
4. How much do you weigh?

    _____

    _____
5. What is your race?
    a. Black
    b. White
    c. Hispanic
    d. Asian
    e. Other
6. Do you smoke?
    a. Yes
    b. No
7. Have you been diagnosed with any mental health issues? (ex. anxiety, depression, etc.)
    a. Yes
    b. No
8. Are you on any additional medications? (ex. cholesterol, blood pressure, depression etc.)
    a. Yes
    b. No
9. Have you consumed alcohol in the last 24 hours?
    a. Yes
    b. No
10. Have you used a pre-workout supplement within the last 24 hour?
    a. Yes
    b. No
11. Have you had a musculoskeletal injury in the last 6 months? (ex. sprains, strains, etc)
    a. Yes
    b. No
12. Have you had a head injury in the last 6 months? (ex. Concussion)
    a. Yes
    b. No
13. Do you meet the criteria for recreationally active? (i.e. participating in some form of physical activity for 20 min three times per week.)
    a. Yes
    b. No
14. How many hours of sleep did you receive last night?

    _____

    _____
15. Do you currently take ADHD medication?
    a. Yes
    b. No

If number 15 is answered yes please answer the following questions.

16. Who diagnosed you with ADHD? (ex. pediatric doctor, psychologist, etc.)

17. What is the name of the medication you are prescribed?

18. How long have you been on ADHD medication?

19. How regularly do you take your medication?

20. Do you feel as if your medication helps you in ATHLETIC ACTIVITES?

    a. Yes
    b. No

Exclusion Criteria

- No musculoskeletal or head injuries within the last 6 months
- Patients prescribed non-stimulant medication
- Mental health comorbidities (anxiety, depression)
- No other prescribed medication for other comorbidities (sleep disturbances)
- Smoking
- Use of alcohol or recreational drugs within 24 hours of testing

FOR THE RESEARCHER USE ONLY

Dominant Hand:_____

Distance from Dynavision: _____

Mode D:

Horizontal

Visual	Px:	1:	2:	3:	4:	5:	6:	7:
Motor	Px:	1:	2:	3:	4:	5:	6:	7:

Circle

Visual	Px:	1:	2:	3:	4:	5:	6:	7:
Motor	Px:	1:	2:	3:	4:	5:	6:	7:

Direct

Visual	Px:	1:	2:	3:	4:	5:	6:	7:
Motor	Px:	1:	2:	3:	4:	5:	6:	7:

Mode A: Px: ____ Px:____ Px: ____ 1: ____ 2: ____ 3: ____ 4: ____ 5: ____

_____

Mode D:

Horizontal

Visual	Px:	1:	2:	3:	4:	5:	6:	7:
Motor	Px:	1:	2:	3:	4:	5:	6:	7:

Circle

Visual	Px:	1:	2:	3:	4:	5:	6:	7:
Motor	Px:	1:	2:	3:	4:	5:	6:	7:

Direct

Visual	Px:	1:	2:	3:	4:	5:	6:	7:
Motor	Px:	1:	2:	3:	4:	5:	6:	7:

Mode A: Px: ____ Px:____ Px: ____ 1: ____ 2: ____ 3: ____ 4: ____ 5: ____

Post Dynavision Effort Scale

1. How hard did you try?

0 1 2 3 4 5 6

Did not try at all Tried my hardest

First Test Session Answers:
1)

2)

3)

Second Test Session Answers:
1)

2)

3)

Script

Validation of medication:

- If the participant is supposed to be on medication: Did you take your medication today?
- If the participant is supposed to be off medication: Did you not take your medication today?

Mode D

- Which hand is your dominant hand? You will be using your dominant hand for the all tasks of the Mode D test.

- Please stand in a comfortable position in front of the LCD screen. The spot you choose will be measured from the board to the tip of the toes.
- The screen will be adjusted to the height of the participant, where the LCD screen is in front of their eyes and they will be able to reach all of the potential stimuli.
- For this test you will have one practice trial before each of the three tasks.
- For the first task you will have to respond to stimuli in a horizontal line. To start this task you will hold down the home button. Once holding down this button a new stimulus will appear in a horizontal line (point to potential stimuli) in a matter of 2-4 seconds. Once you see a new stimulus remove your finger from the home button and press the new stimulus as quickly as you can. After you respond to the one stimuli, wait for me to instruct you to hold down the red button again to start the next stimulus. After the one practice trial you will repeat this 7 times.
- When the 7 trials are completed I will progress you to the next task.
- You will be given 30 seconds rest before starting the next task.
- For the second task you will be responding to the stimuli in a circle (point to potential stimuli). Again, you will hold down the home button to start the task. Within 2-4 seconds a new stimulus will appear and you must try to strike it as quickly as possible. After you respond to the one stimuli, wait for me to instruct you to hold down the red button again to start the next stimulus. After the one practice trial you will repeat this 7 times. You will be given 30 seconds of rest before starting the next task.
- For the final task you will be responding to a direct stimulus. You will know before the test starts which button you will need to hit. Once holding down the home button the new stimulus will appear in a matter of 2-4 seconds. You will perform one practice trial followed by 7 stimuli, again striking the new stimulus as quickly as possible. After you respond to the one stimuli, wait for me to instruct you to hold down the red button again to start the next stimulus.
- This concludes this portion of the testing.

Mode A

- Please stand in a comfortable position where you are able to reach both sides as well as the top and the bottom of the board with both hands.
- For this test you will be allowed to use both hands for this test. You will also be allowed to either use the front or the back of your hand. Whichever you choose you will need to continue with that method for the entity of the test and the next test session.
- For this test you must try your hardest to continuously look at the LCD screen. (this will be repeated before each of the test trials begin.
- The LCD screen will countdown from 5 and a red button will light up. You must try to strike that button as quickly as you can. Once the button is struck, the red light will move to a different part of the board, where again you must try to strike the button as quickly as you can. This process will continue for a total of 1 minute. You will perform 3 practice trials followed by 5 test trials. Again, you must try to hit the buttons as quickly as possible while keeping your eye sight on the LCD screen.

Effort Debriefing

- If you had to rank how hard you tried on a 0-6 scale, 0 being not trying at all and 6 being you put forth your best effort, how would you rank your efforts?
    - Where there any points in which you felt you stopped trying your hardest? If so, which sections?
    - Did you feel as if you lost attention/interest during any of the testing sessions? If, so which sections?
    - Do you feel your loss of attention/ interest affected your effort?

REFERENCES

1. Association AP. *Diagnostic and Statistical Manual of Mental Disorders*. Vol 5th. Washington, DC: American Psychiatric Association; 2013.

2. Childress AC, Berry SA. Pharmacotherapy of Attention-Deficit Hyperactivity Disorder in Adolescents. *Drugs*. 2012;72(3):309-325.

3. Rowland AS, Lesesne CA, Abramowitz AJ. The epidemiology of attention-deficit/hyperactivity disorder(ADHD): A public health view. *Ment Retard Dev Disabil Res Rev*. 2002;8(3):162-170. doi:10.1002/mrdd.10036.

4. Conant-Norville DO. ADHD and youth sports: a small opinion survey of child psychiatrists. *Present Int Soc Sport Psychiatry Annu Scienrific Meet*. May 2005.

5. Berger I. Diagnosis of Attention Deficit Hyperactivity Disorder: Much Ado about Something. *Isr Med Assoc J*. 2011;13(9):571-574.

6. Cortese S. The neurobiology and genetics of Attention-Deficit/Hyperactivity Disorder (ADHD): What every clinician should know. *Eur J Paediatr Neurol*. 2012;16(5):422-433. doi:10.1016/j.ejpn.2012.01.009.

7. Arnsten AFT, Pliszka SR. Catecholamine influences on prefrontal cortical function: Relevance to treatment of attention deficit/hyperactivity disorder and related disorders. *Pharmacol Biochem Behav*. 2011;99(2):211-216. doi:10.1016/j.pbb.2011.01.020.

8. Kesner RP, Churchwell JC. An analysis of rat prefrontal cortex in mediating executive function. *Neurobiol Learn Mem*. 2011;96(3):417-431. doi:10.1016/j.nlm.2011.07.002.

9. Attention-Deficit/Hyperactivity Disorder (ADHD): Data & Statistics. http://www.cdc.gov/ncbddd/adhd/data.html.

10. Hickey G, Fricker P. Attention deficit hyperactivity disorder, CNS stimulants and sport. *Sports Med*. 1999;27(1):11-21. doi:10.2165/00007256-199927010-00002.

11. Kessler RC, Adler L, Barkley R, et al. The prevalence and correlates of adult ADHD in the United States: Results from the National Comorbidity Survey Replication. *Am J Psychiatry*. 2006;163(4):716-723. doi:10.1176/appi.ajp.163.4.716.

12. Barkley RA. The North American Perspective On Attention Deficit Hyperactivity Disorder. *Educ Dev Psychol*. 1996;13(1):2–23. doi:10.1017/S0816512200027358.

13. Wade MG. EFFECTS OF METHYLPHENIDATE ON MOTOR SKILL ACQUISITION OF HYPERACTIVE-CHILDREN. *J Learn Disabil*. 1976;9(7):443-447.

14. Moffitt TE. JUVENILE-DELINQUENCY AND ATTENTION DEFICIT DISORDER - BOYS DEVELOPMENTAL TRAJECTORIES FROM AGE 3 TO AGE 15. *Child Dev*. 1990;61(3):893-910. doi:10.1111/j.1467-8624.1990.tb02830.x.

15. Harvey WJ, Reid G. Motor performance of children with attention-deficit hyperactivity disorder: A preliminary investigation. *Adapt Phys Act Q*. 1997;14(3):189-202.

16. Harvey WJ, Reid G, Grizenko N, Mbekou V, Ter-Stepanian M, Joober R. Fundamental movement skills and children with attention-deficit hyperactivity disorder: Peer comparisons and stimulant effects. *J Abnorm Child Psychol*. 2007;35(5):871-882. doi:10.1007/s10802-007-9140-5.

17. Del Rossi G, Malaguti A, Del Rossi S. Practice Effects Associated With Repeated Assessment of a Clinical Test of Reaction Time. *J Athl Train*. 2014;49(3):356-359. doi:10.4085/1062-6059-49.2.04.

18. Eckner JT, Richardson JK, Kim H, Joshi MS, Oh YK, Ashton-Miller JA. RELIABILITY AND CRITERION VALIDITY OF A NOVEL CLINICAL TEST OF SIMPLE AND COMPLEX REACTION TIME IN ATHLETES. *Percept Mot Skills*. 2015;120(3):841-859. doi:10.2466/25.15.PMS.120v19x6.

19. Luce R. Response times: their role in inferring elementary mental organization. *Psychometrika*. 1989;54(3):542-545.

20. Welford A. Chocie reaction time: Basic concepts. *React Times*. 1980:73-128.

21. Epstein JN, Keith Conners C, Hervey AS, et al. Assessing medication effects in the MTA study using neuropsychological outcomes. *J Child Psychol Psychiatry*. 2006;47(5):446-456. doi:10.1111/j.1469-7610.2005.01469.x.

22. Kaiser M-L, Schoemaker MM, Albaret J-M, Geuze RH. What is the evidence of impaired motor skills and motor control among children with attention deficit hyperactivity disorder (ADHD)? Systematic review of the literature. *Res Dev Disabil*. 2015;36:338-357. doi:10.1016/j.ridd.2014.09.023.

23. Kofler MJ, Rapport MD, Sarver DE, et al. Reaction time variability in ADHD: A meta-analytic review of 319 studies. *Clin Psychol Rev*. 2013;33(6):795-811. doi:10.1016/j.cpr.2013.06.001.

24. Alderson RM, Rapport MD, Kofler MJ. Attention-Deficit/Hyperactivity disorder and behavioral inhibition: A meta-analytic review of the stop-signal paradigm. *J Abnorm Child Psychol*. 2007;35(5):745-758. doi:10.1007/s10802-007-9131-6.

25. Buzy WM, Medoff DR, Schweitzer JB. Intra-Individual Variability Among Children with Adhd on a Working Memory Task: An Ex-Gaussian Approach. *Child Neuropsychol*. 2009;15(5):441-459. doi:10.1080/09297040802646991.

26. Klein C, Wendling K, Huettner P, Ruder H, Peper M. Intra-subject variability in attention-deficit hyperactivity disorder. *Biol Psychiatry*. 2006;60(10):1088-1097. doi:10.1016/j.biopsych.2006.04.003.

27. Willcutt EG, Sonuga-Barke EJS, Nigg JT, Sergeant JA. Recent developments in neuropsychological models of childhood psychiatric disorders. In: Banaschewski T, Rohde LA, eds. *Advances in Biological Psychiatry*. Vol 24. Willcutt, Erik G.; Univ Colorado, Dept Psychol, Inst Behav Genet, UCB 345, Boulder, CO 80309 USA; 2008:195-226.

28. Hervey AS, Epstein JN, Curry JF, et al. Reaction time distribution analysis of neuropsychological performance in an ADHD sample. *Child Neuropsychol*. 2006;12(2):125-140. doi:10.1080/09297040500499081.

29. Leth-Steensen C, Elbaz ZK, Douglas VI. Mean response times, variability, and skew in the responding of ADHD children: a response time distributional approach. *Acta Psychol (Amst)*. 2000;104(2):167-190. doi:10.1016/S0001-6918(00)00019-6.

30. Epstein JN, Hwang ME, Antonini T, Langberg JM, Altaye M, Arnold LE. Examining predictors of reaction times in children with ADHD and normal controls. *J Int Neuropsychol Soc*. 2010;16(1):138-147. doi:10.1017/S1355617709991111.

31. Tamm L, Narad ME, Antonini TN, O'Brien KM, Hawk LW Jr, Epstein JN. Reaction Time Variability in ADHD: A Review. *Neurotherapeutics*. 2012;9(3):500-508. doi:10.1007/s13311-012-0138-5.

32. Abikoff H, Hechtman L, Klein RG, et al. Symptomatic improvement in children with ADHD treated with long-term methylphenidate and multimodal psychosocial treatment. *J Am Acad Child Adolesc Psychiatry*. 2004;43(7):802-811. doi:10.1097/01.chi.0000128791.10014.ac.

33. Riccio CA, Reynolds CR, Lowe PA. *Clinical Applications of Continuous Performance Tests: Measuring Attention and Impulsive Responding in Children and Adults*. Vol xii. Hoboken, NJ, US: John Wiley & Sons Inc; 2001.

34. Sharma A, Couture J. A Review of the Pathophysiology, Etiology, and Treatment of Attention-Deficit Hyperactivity Disorder (ADHD). *Ann Pharmacother*. 2014;48(2):209-225. doi:10.1177/1060028013510699.

35. Wilens TE, Spencer TJ. The stimulants revisited. *Child Adolesc Psychiatr Clin N Am*. 2000;9(3):573-+.

36. Wilens T, Biederman J. The Stimulants. *Psychiatr Clin North Am*. 1992;15(1):191-222.

37. Wilens TE, Morrison NR, Prince J. An update on the pharmacotherapy of attention-deficit/hyperactivity disorder in adults. *Expert Rev Neurother*. 2011;11(10):1443-1465. doi:10.1586/ern.11.137.

38. Conant-Norville DO, Tofler IR. Attention deficit/hyperactivity disorder and psychopharmacologic treatments in the athlete. *Clin Sports Med*. 2005;24(4):829-+. doi:10.1016/j.csm.2005.05.007.

39. Centers for Disease Control and Prevention (CDC). Mental health in the United States. Prevalence of diagnosis and medication treatment for attention-deficit/hyperactivity disorder--United States, 2003. *MMWR Morb Mortal Wkly Rep*. 2005;54(34):842-847.

40. Jacobvitz D, Sroufe LA, Stewart M, Leffert N. TREATMENT OF ATTENTIONAL AND HYPERACTIVITY PROBLEMS IN CHILDREN WITH SYMPATHOMIMETIC DRUGS - A COMPREHENSIVE REVIEW. *J Am Acad Child Adolesc Psychiatry*. 1990;29(5):677-688. doi:10.1097/00004583-199009000-00001.

41. Pelham W, Harper G, Mcburnett K, et al. Methylphenidate and Baseball Playing in Adhd Children - Whos on 1st. *J Consult Clin Psychol*. 1990;58(1):130-133.

42. Wells AJ, Hoffman JR, Gonzalez AM, et al. Phosphatidylserine and caffeine attenuate postexercise mood disturbance and perception of fatigue in humans. *Nutr Res N Y N*. 2013;33(6):464-472. doi:10.1016/j.nutres.2013.03.009.

43. Klavora P, Gaskovski P, Forsyth RD. TEST-RETEST RELIABILITY OF 3 DYNAVISION TASKS. *Percept Mot Skills*. 1995;80(2):607-610.

44. Wells AJ, Hoffman JR, Beyer KS, et al. Reliability of the Dynavision (TM) D2 for Assessing Reaction Time Performance. *J Sports Sci Med*. 2014;13(1):145-150.

45. Klavora P, Gaskovski P, Heslegrave RJ, Quinn RP, Young M. Rehabilitation of Visual Skills Using the Dynavision: A Single Case Experimental Study. *Can J Occup Ther*. 1995;62(1):37-43. doi:10.1177/000841749506200107.

46. Klotz JM, Johnson MD, Wu SW, Isaacs KM, Gilbert DL. Relationship between reaction time variability and motor skill development in ADHD. *Child Neuropsychol*. 2012;18(6):576-585. doi:10.1080/09297049.2011.625356.

47. Rommelse NNJ, Altink ME, Oosterlaan J, et al. Motor control in children with ADHD and non-affected siblings: deficits most pronounced using the left hand. *J Child Psychol Psychiatry*. 2007;48(11):1071-1079. doi:10.1111/j.1469-7610.2007.01781.x.

48. Rosch KS, Dirlikov B, Mostofsky SH. Increased Intrasubject Variability in Boys with ADHD Across Tests of Motor and Cognitive Control. *J Abnorm Child Psychol*. 2013;41(3):485-495. doi:10.1007/s10802-012-9690-z.

49. Jadad AR, Boyle M, Cunningham C, Kim M, Schachar R. Treatment of attention-deficit/hyperactivity disorder. *Evid Rep Technol Assess (Summ)*. 1999;(11):i-viii, 1-341.

50. Knights RM, Hinton GG. EFFECTS OF METHYLPHENIDATE (RITALIN) ON MOTOR SKILLS AND BEHAVIOR OF CHILDREN WITH LEARNING PROBLEMS. *J Nerv Ment Dis*. 1969;148(6):643-. doi:10.1097/00005053-196906000-00008.

51. Sheppard DM, Bradshaw JL, Georgiou N, Bradshaw JA, Lee P. Movement sequencing in children with Tourette's syndrome and attention deficit hyperactivity disorder. *Mov Disord*. 2000;15(6):1184-1193. doi:10.1002/1531-8257(200011)15:6<1184::AID-MDS1018>3.0.CO;2-N.

52. Arm Movement Control: Differences between Children with and without Attention Deficit Hyperactivity Disorder. ResearchGate. https://www.researchgate.net/publication/11439810_Arm_Movement_Control_Differences_between_Children_with_and_without_Attention_Deficit_Hyperactivity_Disorder. Accessed March 20, 2017.

53. Sergeant J. The cognitive-energetic model: an empirical approach to attention-deficit hyperactivity disorder. *Neurosci Biobehav Rev*. 2000;24(1):7-12.

54. Sergeant JA, Meere JJ van der. Ritalin: An energetic factor? 2000. https://research.vu.nl/en/publications/ritalin-an-energetic-factor. Accessed March 5, 2017.

55. Nutt D, King LA, Saulsbury W, Blakemore C. Development of a rational scale to assess the harm of drugs of potential misuse. *Lancet*. 2007;369(9566):1047-1053. doi:10.1016/s0140-6736(07)60464-4.

56. Pitcher TM, Piek JP, Hay DA. Fine and gross motor ability in males with ADHD. *Dev Med Child Neurol*. 2003;45(8):525-535.

57. Hervey AS, Epstein JN, Curry JF. Neuropsychology of adults with attention-deficit/hyperactivity disorder: A meta-analytic review. *Neuropsychology*. 2004;18(3):485-503. doi:10.1037/0894-4105.18.3.485.

58. Schoechlin C, Engel RR. Neuropsychological performance in adult attention-deficit hyperactivity disorder: Meta-analysis of empirical data. *Arch Clin Neuropsychol*. 2005;20(6):727-744. doi:10.1016/j.acn.2005.04.005.

59. Willcutt EG. The Prevalence of DSM-IV Attention-Deficit/Hyperactivity Disorder: A Meta-Analytic Review. *Neurotherapeutics*. 2012;9(3):490-499. doi:10.1007/s13311-012-0135-8.

60. Riemann BL, Tray NC, Lephart SM. Unilateral multiaxial coordination training and ankle kinesthesia, muscle strength, and postural control. *J Sport Rehabil*. 2003;12(1):13-30.

61. Barkley RA. Genetics of childhood disorders: XVII. ADHD, part 1: The executive functions and ADHD. *J Am Acad Child Adolesc Psychiatry*. 2000;39(8):1064-1068. doi:10.1097/00004583-200008000-00025.

62. Shaw P, Eckstrand K, Sharp W, et al. Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. *Proc Natl Acad Sci U S A*. 2007;104(49):19649-19654. doi:10.1073/pnas.0707741104.

63. Robbins TW. Dopamine and cognition. *Curr Opin Neurol*. 2003;16:S1-S2. doi:10.1097/00019052-200312002-00001.

64. Pliszka SR. The neuropsychopharmacology of attention-deficit/hyperactivity disorder. *Biol Psychiatry*. 2005;57:1385-1390.

65. Tripp G, Wickens JR. Neurobiology of ADHD. *Neuropharmacology*. 2009;57(7-8):579-589. doi:10.1016/j.neuropharm.2009.07.026.

66. Froehlich TE, Lanphear BP, Epstein JN, Barbaresi WJ, Katusic SK, Kahn RS. Prevalence, recognition, and treatment of attention-deficit/hyperactivity disorder in a national sample of US children. *Arch Pediatr Adolesc Med*. 2007;161(9):857-864. doi:10.1001/archpedi.161.9.857.

67. Polanczyk G, de Lima MS, Horta BL, Biederman J, Rohde LA. The worldwide prevalence of ADHD: A systematic review and metaregression analysis. *Am J Psychiatry*. 2007;164(6):942-948. doi:10.1176/appi.ajp.164.6.942.

68. Safer DJ, Krager JM. A SURVEY OF MEDICATION TREATMENT FOR HYPERACTIVE INATTENTIVE STUDENTS. *Jama-J Am Med Assoc*. 1988;260(15):2256-2258. doi:10.1001/jama.260.15.2256.

69. Harel EH, Brown WD. Attention deficit hyperactivity disorder in elementary school children in Rhode Island: Associated psychosocial factors and medications used. *Clin Pediatr (Phila)*. 2003;42(6):497-503. doi:10.1177/000992280304200603.

70. Pelham WE, Foster EM, Robb JA. The economic impact of Attention-Deficit/Hyperactivity disorder in children and adolescents. *J Pediatr Psychol*. 2007;32(6):711-727. doi:10.1093/jpepsy/jsm022.

71. Biederman J, Monuteaux MC, Mick E, et al. Young adult outcome of attention deficit hyperactivity disorder: a controlled 10-year follow-up study. *Psychol Med*. 2006;36(2):167-179. doi:10.1017/S0033291705006410.

72. Adler LA, Barkley RA, Newcorn JH. Performance improvement CME: adult ADHD. *J Clin Psychiatry*. 2011;72(4):e15-e15. doi:10.4088/JCP.9066pi4c.

73. Modesto-Lowe V, Meyer A, Soovajian V. A clinican's guide to adult attention-deficit hyperactivity disorder. *Conn Med*. 2012;76(9):517-523.

74. Maul J, Advokat C. Stimulant medications for attention-deficit/hyperactivity disorder (ADHD) improve memory of emotional stimuli in ADHD-diagnosed college students. *Pharmacol Biochem Behav*. 2013;105:58-62. doi:10.1016/j.pbb.2013.01.021.

75. Willens T. Prevalence, diagnosis and issues of comorbididy. *Cns Spectr*. 2007;12(4):3-5.

76. Simon V, Czobor P, Balint S, Meszaros A, Bitter I. Prevalence and correlates of adult attention-deficit hyperactivity disorder: meta-analysis. *Br J Psychiatry*. 2009;194(3):204-211. doi:10.1192/bjp.bp.107.048827.

77. Faraone SV, Biederman J, Mick E. The age-dependent decline of attention deficit hyperactivity disorder: a meta-analysis of follow-up studies. *Psychol Med*. 2006;36(2):159-165. doi:10.1017/s003329170500471x.

78. Karam RG, Breda V, Picon FA, et al. Persistence and remission of ADHD during adulthood: a 7-year clinical follow-up study. *Psychol Med*. 2015;45(10):2045-2056. doi:10.1017/s0033291714003183.

79. Putukian M, Kreher JB, Coppel DB, Glazer JL, McKeag DB, White RD. Attention Deficit Hyperactivity Disorder and the Athlete: An American Medical Society for Sports Medicine Position Statement (vol 21, pg 392, 2011). *Clin J Sport Med*. 2012;22(1):79-79.

80. Spencer T, Biederman J, Wilens TE, Faraone SV. Adults With Attention-Deficit/Hyperactivity Disorder: A Controversial Diagnosis. *J Clin Psychiatry*. 1998;59(suppl 7):59-68.

81. *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision*. 4th edition. Washington, DC: American Psychiatric Association; 2000.

82. Goodman DW, Lasser RA, Babcock T, Pucci ML, Solanto MV. Managing ADHD Across the Lifespan in the Primary Care Setting. *Postgrad Med*. 2011;123(5):14-26. doi:10.3810/pgm.2011.09.2456.

83. Trent S, Davies W. The influence of sex-linked genetic mechanisms on attention and impulsivity. *Biol Psychol*. 2012;89(1):1-13. doi:10.1016/j.biopsycho.2011.09.011.

84. Biederman J, Newcorn J, Sprich S. Comorbidity of Attention-Deficit Hyperactivity Disorder with Conduct, Depressive, Anxiety, and Other Disorders. *Am J Psychiatry*. 1991;148(5):564-577.

85. Pliszka S. Patterns of psychiatric comorbidity with attention-deficit/hyperactivity disorder. *Child Adolesc Psychiatr Clin N Am*. 2009;9(3):525-540.

86. Kessler RC, Adler L, Ames M, et al. The World Health Organization adult ADHD self-report scale (ASRS): a short screening scale for use in the general population. *Psychol Med*. 2005;35(2):245-256. doi:10.1017/S0033291704002892.

87. Barkley RA. *Attention-Deficit Hyperactivity Disorder: A Handbook for Diagnosis and Treatment*. Guilford Publications; 2014.

88. NCAA Banned Drug and Medical Exceptions Policy Guidelines Regarding Medical Reporting for Student-Athletes with Attention Deficit Hyperactivity Disorder (ADHD) Taking Prescribed Stimulants. January 2009. http://drexeldragons.com.s3.amazonaws.com/documents/2009/11/18/NCAA_Guidelines_ADHD_and_ADD.pdf?id=2909.

89. Kehoe W. Treatment of attention defict hyperactivity disorder in children. *Ann Pharmacother*. 2001;57:1130-1134.

90. Dopheide JA. ASHP therapeutic position statement on the appropriate use of medications in the treatment of attention-deficit/hyperactivity disorder in pediatric patients. *Am J Health-Syst Pharm AJHP Off J Am Soc Health-Syst Pharm*. 2005;62(14):1502-1509. doi:10.2146/ajhp040600.

91. Rader R, McCauley L, Callen EC. Current Strategies in the Diagnosis and Treatment of Childhood Attention-Deficit/Hyperactivity Disorder. *Am Fam Physician*. 2009;79(8):657-665.

92. Cohen JA. Practice Parameter for the Assessment and Treatment of Children and Adolescents With Posttraumatic Stress Disorder. *J Am Acad Child Adolesc Psychiatry*. 2010;49(4):414-430. doi:10.1016/j.jaac.2009.12.020.

93. In de Braek D, Dijkstra JB, Jolles J. Cognitive complaints and neuropsychological functioning in adults with and without attention-deficit hyperactivity disorder referred for multidisciplinary assessment. *Appl Neuropsychol*. 2011;18(2):127-135. doi:10.1080/09084282.2011.570614.

94. Psychiatry AAOCAA. Practice parameters for the assessment and treatment of children and adolescents with posttraumatic stress disorder. *J Am Acad Child Adolesc Psychiatry*. 1998;37(10 SUPPL.):4S-26S.

95. Knouse LE, Cooper-Vince C, Sprich S, Safren SA. Recent developments in the psychosocial treatment of adult ADHD. *Expert Rev Neurother*. 2008;8(10):1537-1548. doi:10.1586/14737175.8.10.1537.

96. Knouse LE, Safren SA. Current Status of Cognitive Behavioral Therapy for Adult Attention-Deficit Hyperactivity Disorder. *Psychiatr Clin North Am*. 2010;33(3):497-+. doi:10.1016/j.psc.2010.04.001.

97. Pelham WE, Fabiano GA. Evidence-based psychosocial treatments for attention-deficit/hyperactivity disorder. *J Clin Child Adolesc Psychol*. 2008;37(1):184-214. doi:10.1080/15374410701818681.

98. Chacko A, Wymbs BT, Wymbs FA, et al. Enhancing Traditional Behavioral Parent Training for Single Mothers of Children with ADHD. *J Clin Child Adolesc Psychol*. 2009;38(2):206-218. doi:10.1080/15374410802698388.

99. Pelham WE, Burrows-MacLean L, Gnagy EM, et al. Transdermal methylphenidate, behavioral, and combined treatment for children with ADHD. *Exp Clin Psychopharmacol*. 2005;13(2):111-126. doi:10.1037/1064-1297.13.2.111.

100. Jensen PS, Arnold LE, Swanson JM, et al. 3-year follow-up of the NIMH MTA study. *J Am Acad Child Adolesc Psychiatry*. 2007;46(8):989-1002. doi:10.1097/chi.0b013e3180686d48.

101. Molina BSG, Hinshaw SP, Swanson JM, et al. The MTA at 8 Years: Prospective Follow-up of Children Treated for Combined-Type ADHD in a Multisite Study. *J Am Acad Child Adolesc Psychiatry*. 2009;48(5):484-500. doi:10.1097/CHI.0b013e31819c23d0.

102. Swanson J, Arnold LE, Kraemer H, et al. Evidence, Interpretation, and Qualification From Multiple Reports of Long-Term Outcomes in the Multimodal Treatment Study of Children With ADHD (MTA) Part I: Executive Summary. *J Atten Disord*. 2008;12(1):4-14. doi:10.1177/1087054708319345.

103. Johnston LD, O'Malley PM, Miech RA, Bachman JG, Schulenberg JE. Monitoring the Future national survery results on drug use, 1975-2015: Overview, key findings on adolescent drug use. *Institue Soc Res Univ Mich*. 2016:98.

104. DuPont RL, Coleman JJ, Bucher RH, Wilford BB. Characteristics and motives of college students who engage in nonmedical use of methylphenidate. *Am J Addict*. 2008;17(3):167-171. doi:10.1080/10550490802019642.

105. Spencer T, Biederman J, Wilens T. Nonstimulant treatment of adult attention-deficit/hyperactivity disorder. *Psychiatr Clin North Am*. 2004;27(2):373-+. doi:10.1016/j.psc.2003.12.001.

106. Waxmonsky JG. Nonstimulant therapies for attention-deficit hyperactivity disorder (ADHD) in children and adults. *Essent Psychopharmacol*. 2005;6(5):262-276.

107. Greenhill LL, Halperin JM, Abikoff H. Stimulant medications. *J Am Acad Child Adolesc Psychiatry*. 1999;38(5):503-512. doi:10.1097/00004583-199905000-00011.

108. Shier AC RT Ghuman HS, Ghuman JK. Pharmacological treatment of attention deficit hyperactivity disorder in children and adolescents: clinical strategies. *J Cent Nerv Syst Dis*. 2012;5:1-17.

109. Stevenson RD WM. Stimulant medication therapy in the treatment of children with attention deficit hyperactivity disorder. *Pediatr Clin North Am*. 1989;36:1183-1197.

110. Greenfield B HL. Treatment of attention deficit hyperactivity disorder in adults. *Expert Rev Neurother*. 2005;5:107-121.

111. Ahmann PA, Waltonen SJ, Olson KA, Theye FW, Vanerem AJ, Laplant RJ. PLACEBO-CONTROLLED EVALUATION OF RITALIN SIDE-EFFECTS. *Pediatrics*. 1993;91(6):1101-1106.

112. Vitiello B. Understanding the risk of using medications for attention deficit hyperactivity disorder with respect to physical growth and cardiovascular function. *Child Adolesc Psychiatr Clin N Am*. 2008;17(2):459-+. doi:10.1016/j.chc.2007.11.010.

113. Greydanus DE, Pratt HD, Patel DR. Attention deficit hyperactivity disorder across the lifespan: The child, adolescent, and adult. *Dm Dis--Mon*. 2007;53(2):70-131. doi:10.1016/j.disamonth.2007.01.001.

114. Bymaster FP, Katner JS, Nelson DL, et al. Atomoxetine increases extracellular levels of norepinephrine and dopamine in prefrontal cortex of rat: A potential mechanism for efficacy in Attention Deficit/Hyperactivity Disorder. *Neuropsychopharmacology*. 2002;27(5):699-711. doi:10.1016/s0893-133x(02)00346-9.

115. Chamberlain SR, Muller U, Blackwell AD, Clark L, Robbins TW, Sahakian BJ. Neurochemical modulation of response inhibition and probabilistic learning in humans. *Science*. 2006;311(5762):861-863. doi:10.1126/science.1121218.

116. Greenhill LL, Pliszka S, Dulcan MK, et al. Practice parameter for the use of stimulant medications in the treatment of children, adolescents, and adults. *J Am Acad Child Adolesc Psychiatry*. 2002;41(2 Supplement):26S-49S.

117. Culpepper L, Mattingly G. Challenges in identifying and managing attention-deficit/hyperactivity disorder in adults in the primary care setting: a review of the literature. *Prim Care Companion J Clin Psychiatry*. 2010;12(6). doi:10.4088/PCC.10r00951pur.

118. Galton F. On instruments for (1) testing perception of differences of tint and for (2) determining reaction time. *J Anthropol Inst*. 1899;19:27-29.

119. Marshall WH, Talbot SA, Ades HW. Cortical Response of the Anesthetized Cat to Gross Photic and Electrical Afferent Stimulation. *J Neurophysiol*. 1943;6(1):1-15.

120. Brebner JT, Welford AT. Introduction: an historical background sketch. *ResearchGate*. January 1980. https://www.researchgate.net/publication/240059124_Introduction_an_historical_background_sketch. Accessed February 24, 2016.

121. Ando S, Kida N, Oda S. Practice effects on reaction time for peripheral and central visual fields. *Percept Mot Skills*. 2002;95(3):747-751. doi:10.2466/PMS.95.7.747-751.

122. Volkow ND, Swanson JM. Adult Attention Deficit-Hyperactivity Disorder. *N Engl J Med*. 2013;369(20):1935-1944. doi:10.1056/NEJMcp1212625.

123. Bedard A-CV, Trampush JW, Newcorn JH, Halperin JM. Perceptual and Motor Inhibition in Adolescents/Young Adults With Childhood-Diagnosed ADHD. *Neuropsychology*. 2010;24(4):424-434. doi:10.1037/a0018752.

124. Burton AW, Miller DE. *Movement Skill Assessment*. Human Kinetics; 1998.

125. Alexander J. Hyperactive-Children - Which Sports Have the Right Stuff. *Phys Sportsmed*. 1990;18(4):105-108.

126. Castellanos FX, Sonuga-Barke EJS, Scheres A, Di Martino A, Hyde C, Walters JR. Varieties of attention-deficit/hyperactivity disorder-related intra-individual variability. *Biol Psychiatry*. 2005;57(11):1416-1423. doi:10.1016/j.biopsych.2004.12.005.

127. Corkum P, Siegel L. Is the Continuous Performance Task a Valuable Research Tool for Use with Children with Attention-Deficit-Hyperactivity Disorder. *J Child Psychol Psychiatry*. 1993;34(7):1217-1239. doi:10.1111/j.1469-7610.1993.tb01784.x.

128. Epstein JN, Brinkman WB, Froehlich T, et al. Effects of Stimulant Medication, Incentives, and Event Rate on Reaction Time Variability in Children With ADHD. *Neuropsychopharmacology*. 2011;36(5):1060-1072. doi:10.1038/npp.2010.243.

129. Spencer SV, Hawk LW, Richards JB, Shiels K, Pelham WE, Waxmonsky JG. Stimulant Treatment Reduces Lapses in Attention among Children with ADHD: The Effects of Methylphenidate on Intra-Individual Response Time Distributions. *J Abnorm Child Psychol*. 2009;37(6):805-816. doi:10.1007/s10802-009-9316-2.

130. Safer DJ. Relative cardiovascular safety of psychostimulants used to treat attention-deficit hyperactivity disorder. *J Child Adolesc Psychopharmacol*. 1992;2(4):279-290. doi:10.1089/cap.1992.2.279.

131. Biederman J, Faraone SV, Spencer TJ, Mick E, Monuteaux MC, Aleardi M. Functional impairments in adults with self-reports of diagnosed ADHD: A controlled study of 1001 adults in the community. *J Clin Psychiatry*. 2006;67(4):524-540.

132. Nissen SE. ADHD drugs and cardiovascular risk. *N Engl J Med*. 2006;354(14):1445-1448. doi:10.1056/NEJMp068049.

133. Tannock R, Schachar RJ, Carr RP, Logan GD. DOSE-RESPONSE EFFECTS OF METHYLPHENIDATE ON ACADEMIC-PERFORMANCE AND OVERT BEHAVIOR IN HYPERACTIVE-CHILDREN. *Pediatrics*. 1989;84(4):648-657.

134. Chandler JV, Blair SN. THE EFFECT OF AMPHETAMINES ON SELECTED PHYSIOLOGICAL COMPONENTS RELATED TO ATHLETIC SUCCESS. *Med Sci Sports Exerc*. 1980;12(1):65-69.

135. Bouchard R, Weber AR, Geiger JD. Informed decision-making on sympathomimetic use in sport and health. *Clin J Sport Med*. 2002;12(4):209-224. doi:10.1097/01.JSM.0000017207.22380.FF.

136. Jacobs I, Bell DG. Effects of acute modafinil ingestion on exercise time to exhaustion. *Med Sci Sports Exerc*. 2004;36(6):1078-1082. doi:10.1249/01.MSS.0000128146.12004.4F.

137. Eckner JT, Kutcher JS, Broglio SP, Richardson JK. Effect of sport-related concussion on clinically measured simple reaction time. *Br J Sports Med*. 2014;48(2):112-U175. doi:10.1136/bjsports-2012-091579.

138. Eckner JT, Kutcher JS, Richardson JK. Pilot Evaluation of a Novel Clinical Test of Reaction Time in National Collegiate Athletic Association Division I Football Players. *J Athl Train*. 2010;45(4):327-332. doi:10.4085/1062-6050-45.4.327.

139. MacDonald J, Wilson J, Young J, et al. Evaluation of a Simple Test of Reaction Time for Baseline Concussion Testing in a Population of High School Athletes. *Clin J Sport Med*. 2015;25(1):43-48.

140. Eckner JT, Kutcher JS, Richardson JK. Between-Seasons Test-Retest Reliability of Clinically Measured Reaction Time in National Collegiate Athletic Association Division I Athletes. *J Athl Train*. 2011;46(4):409-414.

141. International D. Experience the Proven Power of Dynavision! http://www.dynavisioninternational.com/. Accessed March 24, 2016.

142. Bigsby K, Mangine RE, Clark JF, et al. EFFECTS OF POSTURAL CONTROL MANIPULATION ON VISUOMOTOR TRAINING PERFORMANCE: COMPARATIVE DATA IN HEALTHY ATHLETES. *Int J Sports Phys Ther*. 2014;9(4):436-446.

143. Sanders E. The Use of a Visual Motor Test to Identify Deficits in Concussed Collegiate Athletes. 2014.

144. Krakauer JW, Ghilardi M-F, Mentis M, et al. Differential cortical and subcortical activations in learning rotations and gains for reaching: a PET study. *J Neurophysiol*. 2004;91(2):924-933. doi:10.1152/jn.00675.2003.

145. Houlihan M, Campbell K, Stelmack RM. Reaction time and movement time as measures of stimulus evaluation and response processes. *Intelligence*. 1994;18(3):289-307. doi:10.1016/0160-2896(94)90031-0.

146. Hunt TN, Ferrara MS, Miller LS, Macciocchi S. The effect of effort on baseline neuropsychological test scores in high school football athletes. *Arch Clin Neuropsychol*. 2007;22:615-621. doi:10.1016/j.acn.2007.04.005.

147. Green P, Rohling ML, Lees-Haley PR, Allen LM III. Effort has a greater effect on test scores than severe brain injury in compensation claimants. *Brain Inj*. 2001;15(12):1045-1060 16p.