DOES COGNITIVE CONTROL AFFECT SUCCESSFUL “SANDBAGGING” OF CONCUSSION SYMPTOMS?

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ABSTRACT

The value of concussion baseline assessments is dependent upon athletes giving their best effort. If an athlete fakes poor performance or “sandbags”, a future injury may go undetected. Therefore, the purpose of this study was to determine if the SportGait concussion baseline assessment detects differences between participants instructed to sandbag and those who are not. Furthermore, I examined whether participants’ cognitive control is related to their ability to fake poor performance on SportGait. Forty-four participants completed two cognitive control tasks, were randomly assigned to “sandbag” or do their best and completed the SportGait baseline concussion assessment. Results revealed that “sandbagging” participants endorsed more concussion symptoms, made more errors on the CPT-3, and demonstrated lower stride power in their gait. However, cognitive control did not predict sandbagging performance. Together these results indicate that SportGait detects sandbagging, but additional investigation of factors including the impact of coaching on faking behaviors is needed.

DEDICATION

This thesis is dedicated to my parents, sister, grandparents, my partner Jaylen and best friends Emily and Tucker for all of their support and encouragement during the past few years. I cannot thank you enough for all of the love and support you have shown.

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LIST OF ABBREVIATIONS

CDC, Center for Disease Control and Prevention

GCS, Glasgow Coma Scale

mTBI, Mild Traumatic Brain Injury

SAC, Standardized Assessment of Concussions

SCAT, Sports Concussion Assessment Tool

BESS, Balance Error Scoring System

ImPACT, Immediate Post Concussion Assessment and Cognitive Test

MC, Mostly Congruent

MI, Mostly Incongruent

RT, Reaction Time

CPT-3, Conners' Continuous Performance Task, 3rd

HRT, Hit reaction time

CHAPTER I

INTRODUCTION

Neuropsychological assessment is critical to identify if athletes experience cognitive deficits following a concussion, which occur when a hit to the head causes the brain to rapidly hit the walls of the skull (Carroll et al., 2004). However, the utility of those assessments is best when neuropsychologists have a clear indication of an athlete's baseline performance (their pre-screen cognitive ability). Accurate interpretation of baseline results informs the field of neuropsychology about concussion symptoms and effective assessment strategies (Carroll et al., 2004). Moreover, accurate interpretation of neuropsychological test performance depends upon the expectation that individuals are putting forth full effort (Kirkwood & Kirk, 2010; Suhr & Gunstad, 1999) both at baseline assessment and after a possible concussion. Indeed, the more accurate an athlete's baseline assessments, the more likely a concussion will be detected if an injury occurs, thus protecting the athlete from sustaining more damage to their brain if they were to return to play while injured (Alsalaheen et al., 2016).

Unfortunately, some athletes may choose to feign poor performance at baseline. Under these circumstances there is a greater likelihood of failing to detect a concussion because the athlete's baseline cognitive ability is artificially low. When feigning poor performance is applied to baseline cognitive assessment in athletes, this phenomenon is commonly known as "sandbagging" (Erdal, 2012; Higgins et al., 2017; Schatz et al., 2017). Imagine that a senior in high school, who has played football all their life, has a chance to be awarded a full-ride scholarship to their top university, however, they must remain healthy and “in-play” for the entire season. This athlete may choose to “sandbag” during their baseline assessment; they would purposefully perform just badly enough that their scores are artificially low, but not so badly that they make their coaches or trainers suspicious. If successful, this would mean that if they were legitimately injured during their season, their post-injury scores would appear to suggest that no negative cognitive impact exists and they would be permitted to return to play (Erdal, 2012).

If an athlete successfully sandbags a concussion baseline assessment and suffers a concussion during their season, this concussion may go undetected. This can put the athlete in danger of experiencing another concussion. Multiple head injuries, whether mild or severe, can impact the structure and overall function of the brain. A major long-term effect of multiple concussions can be chronic traumatic encephalopathy (CTE), a degenerative disease found in people with a history of multiple head injuries (McKee et al., 2013; Pellman et al., 2006). Symptoms may include “irritability, impulsivity, aggression, depression, short-term memory loss and heightened suicidality that usually begins 8-10 years after experiencing repetitive mild traumatic brain injury” (McKee et al., 2013). As many as 100 National Football League (NFL) players have been diagnosed with CTE and it has recently come to light that many have faked their baseline performance. Indeed, Payton Manning, a well-known retired NFL quarterback, confessed that he sandbagged baseline assessments in order to stay in the game (Erdal, 2012).

Individual differences in cognitive control ability may have an impact on who is successful at faking poor performance during a baseline assessment. Cognitive control is a cognitive process that involves the ability to regulate emotions, thoughts, and attention to accurately complete tasks (Cohen, 2017; DaCosta et al., 2020). Individuals with greater cognitive control better regulate their natural behaviors, which could be useful when trying to successfully sustain lower than actual ability on concussion baseline assessments. The purpose of this study is to determine if participants' cognitive control predicts their ability to fake poor cognitive ability on baseline assessment scores.

Concussions in Sports

Regardless of the physical activity, there is a risk of experiencing a hit to the head. If that hit to the head is forceful enough, a traumatic brain injury (TBI) may occur. TBIs are caused by a forceful hit to the head or body that causes the brain to rapidly hit the walls of the skull (Carroll et al., 2004; McNeal & Selekmen, 2017). The impact of the incident and the nature of the brain anatomy will determine the level of severity (mild, moderate, or severe). The most common type of traumatic brain injury is a mild traumatic brain injury (mTBI), or concussion. Symptoms that immediately occur after sport related concussions include headache, blurred vision, dizziness, and confusion (Carroll et al., 2004). Other symptoms may include, fatigue and/or sleep difficulties, irritability, sadness, nervousness, or anxiousness (Carroll et al., 2004). Post-concussion symptoms, such as dizziness and blurred vision, may resolve within fifteen minutes while other symptoms, including balance instability, may persist for at least two weeks and up to three months (Carroll et al., 2004; Guskiewicz, 2003; Howell et al., 2018).

A typical recovery period after a traumatic brain injury is generally dependent upon the severity of the injury. The Center for Disease Control and Prevention (CDC) suggests four broad recovery recommendations for anyone who has a concussion. First, the CDC recommends patients to limit physical and critical thinking activities, get plenty of rest, and avoid participating in activities that may involve risk of another concussion. Secondly, as the patients experience fewer symptoms after the initial incident, the CDC recommends beginning to engage in light activity which may include a gradual return to non-strenuous activities, slowly reintroducing school and work, but limiting screen time and loud music before going to seep. Then, after acclimating to that level of activity, patients can begin to incorporate moderately strenuous physical activity and for students, their regular school schedule. Finally, only once all symptoms have dissipated does the CDC recommend that patients return to their regular physical and mental activities from before their concussive event. Beyond this guidance, six additional steps are recommended for student athletes, beginning with a return to regular school activities and light aerobic activities (no heavy weightlifting). As symptoms continue to dissipate, student athletes can incorporate moderate activity. Doctor's approval is needed for the student athlete to engage in heavy non-contact activity, including lifting weights and more strenuous workout routines. Finally, if there are no lingering symptoms and a doctor approves of the student's condition, the student athlete can return to competitive play (*Traumatic Brain Injury & Concussion*). To detect and assess concussion symptoms and accurately determine the severity of the injury, an athlete needs to complete a pre-season baseline assessment. The CDC recommends that athletes' baseline cognitive abilities be assessed every two years, or after full recovery of a concussion (Prevention, 2015).

There are a variety of assessments that can measure cognitive ability and be used to detect concussion symptoms. First, the Glasgow Coma Scale (GCS) is frequently used to assess cognitive ability after an injury and is used to determine the severity of the brain injury (Curley et al., 2018; Teasdale & Jennett, 1974). However, the GCS does not include a preassessment, or a baseline score since it is typically assessed after an accident has occurred and the person is in a medical setting with access to computerized tomography scans (Curley et al., 2018; Teasdale & Jennett, 1974). However, the GCS is not useful for diagnosing mild traumatic brain injuries because the GCS is only sensitive to more severe traumatic brain injury symptoms, which includes difficulty opening eyes, verbal and motor responses (Teasdale & Jennett, 1974).

To combat the lack of sensitivity when assessing for mild traumatic brain injuries, the Standardized Assessment of Concussion (SAC; McCrea et al., 1997) has been used. The SAC was created as an objective concussion “sideline” assessment that immediately assesses an athlete’s cognitive abilities after a suspected injury (Curley et al., 2018; McCrea, 2001). The SAC instructs athletic trainers to assess the injured athlete in the domains of spatial orientation (time, day and date, location), immediate and delayed recall, and sustained concentration to determine if concussion symptoms are present (McCrea et al., 1997). However, the SAC alone does not provide information about the severity of the suspected concussion (Curley et al., 2018; McCrea, 2001). Instead, it mainly assesses memory deficits following a concussion and does not assess the physical symptoms (McCrea, 2001). Furthermore, the SAC is only a “sideline” assessment, which is useful for athletic trainers to gauge whether a player is expressing immediate concussion symptoms (e.g., confusion). However, a comparison of baseline performance to post-injury does not occur and over time, athletes may learn to anticipate certain questions that are asked post injury.

The Sports Concussion Assessment Tool (SCAT) was created to address the shortcomings of the SAC, to create a standardized sideline assessment of concussion (McCrory et al., 2005; Yengo-Kahn et al., 2016). The SCAT is a concussion assessment tool used to objectively assess athlete’s neurocognitive functioning and symptom assessment pre- and post-suspected injury (McCrory et al., 2005; Yengo-Kahn et al., 2016). The original SCAT assessed athletes’ symptoms, cognitive status, and gross neurological functions (Echemendia et al., 2017; McCrory et al., 2005). In the 2013 revision, the Sports Concussion Assessment Tool – 3

(SCAT3) was designed to incorporate the Glasgow Coma Scale, the immediate and delayed recall section of the Standardized Assessment of Concussions, and the Balance Error Scoring System (BESS) which assesses balance and stability (Yengo-Kahn et al., 2016). The SCAT3 is sensitive (94%) and relatively specific (76%) for detecting mild traumatic brain injuries (Yengo-Kahn et al., 2016). However, even with the 2013 revision, the SCAT3 has been criticized for its lack of specificity, which is potentially due to its detection of other individual differences in athletes, such as age, primary language, and even the presence of disability (Echemendia et al., 2017; Echemendia et al., 2020).

Perhaps the most commonly used concussion assessment is the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) instrument. ImPACT is a concussion screening instrument that is used to assess possible change in cognitive function from baseline, or pre-season, and post-injury to inform return to play decisions for athletes who suffer a suspected head injury (Alsalaheen et al., 2016; Gaudet & Weyandt, 2017; Higgins et al., 2017; Schatz et al., 2017). If an athlete experiences a suspected head injury, the post-injury assessment will be compared to their baseline scores to determine if any significant decline in their cognitive ability is detected. Specifically, ImPACT examines verbal memory, visual memory, visual-motor processing speed, and reaction time (Alsalaheen et al., 2016). ImPACT has strong convergent validity but lacks support in discriminant validity and diagnostic accuracy (Alsalaheen et al., 2016). In addition, a consistent criticism of ImPACT is its lack of effort detection measures, or symptom validity measures (Alsalaheen et al., 2016; DaCosta et al., 2020; Erdal, 2012; Gaudet & Weyandt, 2017; Schatz et al., 2017).

When athletes put forth anything less than their full effort and ability on concussion assessments, the results are not valid. This suboptimal performance may occur because of lack of instruction from athletic trainers, athlete's lack of understanding of instructions, or lack of perceived utility for the baseline tests (Schatz et al., 2017). Any reduction of effort to give their best performance during a baseline assessment will camouflage actual concussion symptoms on a post-injury assessment and result in a failure to detect a concussed state (Bigler, 2014; Covassin et al., 2009). Additionally, while researchers found that 95% of athletic trainers endorsed utilizing ImPACT, only half (55%) of those athletic trainers examined the baseline tests for valid results (Alsalaheen et al., 2016; Higgins et al., 2017). Moreover, some athletic trainers and coaches may even encourage or warn the athletes about behaviors on ImPACT that could lead to an increased likelihood of the athlete being benched for the season if a suspected concussion occurs. This could take the form of athletes being "coached" on how to perform during ImPACT's baseline assessment to 'trick the system.' Coaching behavior may include providing athletes with instructions on how to emulate concussion symptoms, give warnings about what behaviors would be flagged as purposeful faking behavior, and/or told explicit symptoms that are associated with concussions (Erdal, 2004).

Due to concerns about ImPACT's discriminant validity and the potential for coached behaviors, a new concussion assessment, called SportGait, was designed to account for ImPACT's limitations. SportGait is a concussion assessment tool used to compare athletes' baseline performance to post-suspected injury performance (Lecci et al., 2020). The SportGait protocol includes a symptom validity questionnaire, an abbreviated Conners' Continuous Performance Test (CPT-3), and a gait assessment (Lecci et al., 2020). More recently, Lecci and colleagues adapted the SportGait protocol to be used on mobile devices. On the SportGait App the symptom validity questionnaire is used to assess current symptoms (e.g., confusion, dizziness, headaches) and their severity. Athletes are to report any symptoms and their severity at the time of baseline assessment, which may be compared to post-injury assessments. The short CPT-3 requires sustained attention for eight minutes and measures reaction time, response inhibition, and errors of omission (Conners et al., 2003; Lecci et al., 2021). Athletes who experience a head injury will perform poorly on this measure of attention because of their inability to sustain concentration for a prolonged period of time. Postural stability and gait (manner of walking) is assessed by the gait assessment (Lecci et al., 2020). The gait assessment uses phone position monitors to detect speed, power, symmetry, and stride. If a person is concussed, their postural stability, including motor control and coordination, is affected for about three to five days after a mild head injury (Guskiewicz, 2003; Howell et al., 2018; Lecci et al., 2020). Additionally, those who sustain a concussion are likely to have shorter stride length, slower walking pace, and more gait variability as they walk (Howell et al., 2018; Lecci et al., 2020). These symptoms can persist for 28 days and up to one-year post-concussion (Chou et al., 2004; Howell et al., 2018).

When compared to ImPACT, the researchers who utilized the SportGait protocol were able to explain significantly more variation of concussion symptoms in children and young adults, aged 6-17, by using the CPT-3 and gait assessment. Therefore, SportGait better explains baseline and post-injury performance and is a stronger predictor of concussion symptoms when compared to ImPACT (Lecci et al., 2020). Moreover, because SportGait measures gait, balance, and stability it may also be more robust in measuring the subtle errors that concussed athletes make, and it may be more difficult to fake poor performance.

Sandbagging and Suboptimal Effort

Baseline concussion assessments require athletes to give their best performance and full effort to accurately detect concussion symptoms post-suspected injury. Effort is described as the maximal ability of an individual and is examined through their performance on a series of assessments (Bigler, 2014). Suboptimal effort, therefore, is the purposeful act of giving less than maximal performance on neuropsychological tests to influence the results (Kirkwood & Kirk, 2010). Participants' suboptimal performance may be motivated by an external or internal benefit, a lack of motivation, and/or perceived poor utility of the assessment (Erdal, 2012; Kirkwood & Kirk, 2010). People may fake bad performance as a way to express neuropsychological impairment (Mazza et al., 2020). When faking, individuals may exaggerate symptoms on self-reported questionnaires, make purposeful errors, or even withhold behaviors that do not reflect their actual ability (Mazza et al., 2020). Faking, in this sense, is an effortful behavior to directly create inaccurate responses to influence a specific outcome or receive a reward (Ellingson & McFarland, 2011; Mazza et al., 2020).

One commonly reported reason for athletes' putting forth suboptimal effort is to directly influence their eligibility to play within their sport. "Sandbagging" is referred to as an athletes' intentional poor performance on baseline tests to influence their return to play decision after a suspected injury (Erdal, 2012; Higgins et al., 2017; Schatz et al., 2017). An athlete who sandbags their baseline assessment provides intentional false information about their baseline abilities for the purpose of generating undetectable differences when their baseline scores are compared to post-injury behaviors. This may lead to unsafely allowing an athlete to return to play (Erdal, 2012; Gaudet & Weyandt, 2017; Higgins et al., 2017; Schatz et al., 2017). However, sandbagging may alternatively result from a lack of personal interest or motivation, lack of understanding or lack of perceived utility for the tests, which too could lead to invalid test results (Erdal, 2012; Schatz et al., 2017).

Notably, athletes can sandbag the ImPACT baseline assessment without detection (Erdal, 2012). Athletes who were successful at sandbagging revealed their strategy was more focused on producing natural errors than more calculated exaggeration of errors (Erdal, 2012). These natural errors are more subtle than purposeful, calculated exaggerations of concussion-like behavior. Specifically, the participants' sandbagging behavior went undetected on ImPACT's verbal memory, reaction time, and impulse control tasks (Erdal, 2012). An example of a natural error is when participants clicked the response key at a faster rate during assessments of sustained attention to naturally facilitate errors in accuracy but not to directly create inaccurate responses (Erdal, 2012). On the other hand, participants who used the strategy of producing calculated errors described their strategy as making an error every fifth visual stimulus or asking to repeat the instructions twice before beginning a new task (Erdal, 2012).

As mentioned above, sandbagging behaviors can be coached. For example, coached athletes are taught, or given explicit warnings about the baseline assessments as a way to influence the athlete's performance on baseline assessments (Erdal, 2004). Coaching performance for baseline assessments is used to aid the athletes in their attempts to perform poorly on neuropsychological tests. This may occur by providing explicit warnings regarding test content or instruction and modeling of concussed behavior (Erdal, 2004). Several research studies have examined how well ImPACT detects sandbagging in naïve and coached participants. Higgins and colleagues (2017) discussed that 30% of uncoached and 35% of coached non-athlete college participants were successfully able to sandbag without detection, despite ImPACT's effort indicators. Additionally, Gaudet and Weyandt's (2017) review found that up to 35% of the participants who were sandbagging were not detected by ImPACT, and 20% of coached participants went undetected. Further, Schatz and colleagues (2017) found that ImPACT's built-in effort indicators successfully identified 70% of naïve and 65% of coached sandbaggers (Schatz et al., 2017). Even though athletes can be coached to sandbag on a baseline assessment, some individuals were better sandbaggers than others. This discrepancy may be due to the fact that deceiving others is cognitively demanding, as it generates an internal conflict between typical, or truthful, behavior and the fake, or lying, responses that one is trying to portray (Kasten et al., 2020; Vrij et al., 2017).

Cognitive Control

As we move through our day, most activities are completed relatively automatically and are controlled through bottom-up processing. These behaviors are rapid, stimulus driven responses that occur as we engage with our environment (Nigg, 2017). In other words, they are responses to our environment that occur beneath our awareness, almost like we are driving on autopilot. At times however, we engage with our environment through effortful behavioral control. These effortful behaviors involve deliberate and conscious processing of information (Nigg, 2017) and are slower, capacity limited, and demand working memory resources (Cohen, 2017).

Cognitive control, sustains many of those effortful behaviors, allows us to stay on task by adjusting behaviors to fit a goal or to maintain task-relevant behaviors (Bugg, 2014; Nigg, 2017). Cognitive control includes the ability to shift, update, monitor, and inhibit irrelevant, reactive responses and is highly dependent upon working memory and conflict monitoring (Bugg, 2014; De Lissnyder et al., 2012; Gabrys et al., 2018; Maier et al., 2019; Miyake et al., 2000; Nigg, 2017). Working memory is our ability to hold information in our short-term memory while monitoring incoming information to update our thoughts and behaviors (Miyake et al., 2000; Nigg, 2017). Additionally, as information is updated and is monitored, we can block irrelevant responses to complete a goal (Bugg, 2014; De Lissnyder et al., 2012; Miyake et al., 2000; Nigg, 2017).

In order for cognitive control to be elicited, a conflict must be present (Cohen, 2017; Nigg, 2017). Such conflicts may include a response conflict (two responses have been primed; e.g., Stroop Task), perceptual conflict (interference of task-irrelevant information), cognitive conflict (interference from an irrelevant thought), or goal conflict through switching tasks (Nigg, 2017). The color word Stroop task (Stroop, 1935) is a commonly used measure of cognitive control where participants are presented with a color word (BLUE) viewed in different font colors (BLUE/BLUE). Trials may consist of congruent pairings (the presented color of the word matches the word meaning), or incongruent pairings (the presented color of the word does not match the word meaning) (Bugg, 2014; Cohen, 2017; Stroop, 1935). As each word is presented, participants are asked to respond by pressing a key that matches the font color of the word, inhibiting the intuitive response of reporting the meaning of the word. The Stroop task measures cognitive control, specifically the ability to resolve a response conflict, because the participant must inhibit the natural response to read the presented word, and instead respond to the font color of the word.

There are several assumptions used to explain the mechanisms behind cognitive control. First, we assume that cognitive control is limited in capacity (Cohen, 2017; Nigg, 2017). In other words, performance on one task will suffer when an unrelated task or behavior involves the same stimuli, or responses must be performed simultaneously. To examine cognitive control, tasks that require updating and inhibiting prepotent responses (e.g., Stroop Task, Wisconsin Card Sort task, and Go/No-Go task) are used to measure participants' accuracy and reaction time (Bugg, 2014; Cohen, 2017; Gabrys et al., 2018). In such tasks participants must prioritize accuracy or speed of responses when presented with a trial that presents a conflict (e.g., an incongruent trial). Those who can resolve the conflict quickly while also preserving their accuracy demonstrate higher cognitive control capabilities.

Second, we assume that sustaining cognitive control of goal-directed behavior requires a significant amount of motivation. Indeed, motivation is key to sustaining long periods of self-control over behaviors, completing a task in a timely manner, or conserving effort in anticipation of more demanding tasks later on (Cohen, 2017; Muraven et al., 2006; Nigg, 2017). Motivation is especially important when completing lengthy assessments, like concussion baseline assessments such as SportGait. Cognitive control and motivation must be sustained throughout the entire assessment to gather the most accurate baseline information from each athlete (Erdal, 2012). Ellingson and McFarland (2011) described the Valence-Instrumentality-Expectancy (VIE) theory in relation to faking behavior. VIE theory suggests that a person is required to first, value the possible outcome of a task (e.g., a reward), second, believe that the outcome relies on the success of a behavior (e.g., faking poor performance) and third, that the behavior is achievable (Ellingson & McFarland, 2011). In other words, a person must be motivated to fake their performance to receive the reward that follows.

One deceptively easy task that requires sustained cognitive control and motivation, is the Flanker task. The Flanker task presents participants with rows of arrow stimuli where the central arrow is either congruent (e.g., >>>>>) or incongruent (e.g., >><>>) with the flanking arrows pointing to the left or right (Bugg, 2014; Krenn et al., 2018; Ridderinkhof et al., 2021).

Participants are instructed to determine what direction the center arrow is facing and to respond as quickly and as accurately as possible (Bugg, 2014; Ridderinkhof et al., 2021). Researchers have shown that participants tend to respond faster and more accurately during congruent trials while individuals with poor inhibitory control will have slower reaction time, and more errors, to incongruent trials (Bugg, 2014; Krenn et al., 2018; Ridderinkhof et al., 2021).

Regardless of the tasks being utilized, cognitive control and effort are both at work when people complete tasks such as lengthy neuropsychological assessments like ImPACT and SportGait. Researchers have consistently mentioned limitations for concussion assessments which include participants' general effort, their perceived utility of the test(s), their motivation to accurately complete the task, and previous exposure to the protocol of assessments (DaCosta et al., 2020; Erdal, 2012; Gaudet & Weyandt, 2017; Schatz et al., 2017). Additionally, athletes who are highly motivated to sandbag their baseline assessment may have more cognitive resources available to successfully control and inhibit their instinctual behaviors and to use successful strategies, such as natural error response patterns (Erdal, 2012; Kool et al., 2017; Muraven et al., 2006). But sandbagging is not as easily completed as one might think. Because cognitive control is limited (Cohen, 2017; Nigg, 2017) and deception is mentally taxing (Kasten et al., 2020; Vrij et al., 2017), those who sandbag may need to utilize greater cognitive control to sustain their poor performance. Sandbagging requires inhibiting the prepotent behaviors (e.g., trying one's best) and enhancing controlled behaviors (e.g., behaving in such a way to simulate mild concussive symptoms). Therefore, the difference between the individuals who are successful at sustaining sandbagging throughout neuropsychological assessments may also demonstrate stronger cognitive control ability.

Present Study and Hypotheses

This study examined the influence of cognitive control on participants' ability to successfully sandbag mild concussion symptoms during a baseline assessment. Previous research has examined the influence of cognitive control on inhibiting behaviors during cognitive assessments (Bugg, 2014; King et al., 2007). The impact of cognitive control, as an individual difference, has not been examined with concussion baseline assessments. To examine the impact of individual differences in cognitive control on one's ability to sandbag on a baseline concussion protocol, the following research questions were addressed: First, how will performance on cognitive and gait assessments differ between participants who were instructed to perform at their best and those who were instructed to sandbag? I hypothesized that those assigned to sandbag would endorse more concussion symptoms, make more errors, and be slower overall on the CPT-3, and demonstrate more variability in gait when compared to those in the control group who were instructed to perform at their best.

A second research question for this study was, will performance on the cognitive and gait assessments differ in those with greater cognitive control who were instructed to sandbag in comparison to those with lower cognitive control? Specifically, I hypothesized that participants with greater cognitive control would be more successful sandbaggers than those who are lower in cognitive control because they would demonstrate more reaction time slowing and variability (versus overt errors) on the CPT-3, and more gait asymmetry and instability (versus staggering or tripping) on the gait assessment.

CHAPTER II

METHODOLOGY

Participants

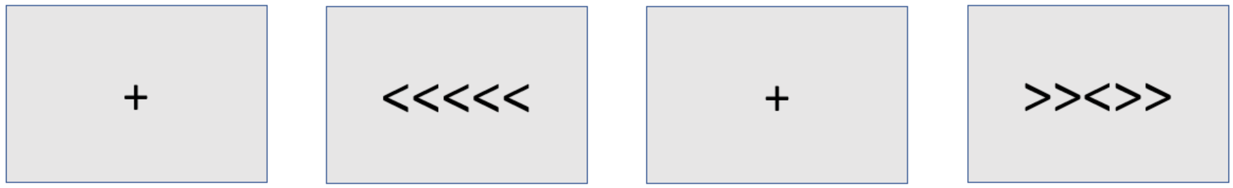
A total of 44 university students aged 18-32 years old (*M* = 21.91, *SD* = 3.17) completed this study. Most of the participants were white (n = 27), and the majority were female (n = 39). Over half of the participants indicated a history of playing high school sports (n = 32; 72.7%), however, only three (6.8%) reported playing in collegiate club sports. Participants who indicated playing a sport in high school and/or a collegiate club sport played soccer, baseball/softball, rugby, track and field, volleyball, cheerleading, basketball, tennis/pickleball, color guard, dance, ultimate frisbee, martial arts, wrestling, mountain biking/BMX and/or swimming. Previous and current sports participation was used as a demographic variable but was not a requirement to participate in this study. Participants were excluded from this study if they had any of the following: 1) experienced a concussion within the last 90 days, 2) had seizures, 3) experience color deficiency, and 4) were younger than 18 years old. The participants were recruited using the SONA research platform for undergraduate psychology students. SONA research participants were awarded extra credit for the psychology course of their choosing and as well as a $5 gift card. This study was approved by the University of Tennessee at Chattanooga Institutional Review Board #21-115 (see Appendix A).

Measures and Procedure

Cognitive Control

Flanker Task. After providing informed consent, participants first completed the Flanker task (Eriksen & Eriksen, 1974), which was one of the measures of cognitive control used in this study. Participants completed counterbalanced blocks of trials that featured mostly congruent (MC) or mostly incongruent (MI) left and right arrow heads (see Figure 1; Bugg, 2014; Eriksen & Erikson, 1974). A congruent flanker trial consisted of five arrowheads pointing in the same direction (e.g., <<<<<). An incongruent flanker trial consisted of five arrowheads with the center arrowhead pointing in an opposite direction (e.g., <<><<). The participants worked through three blocks of trials for a total of 312 trials. The first block had 24 practice flanker trials, 20 of which were congruent and four were incongruent. After the practice trials, the participants completed either the MC block or the MI block, which were counterbalanced. The MC block had 144 trials where 80% were congruent and 20% were incongruent. The MI block consisted of 144 trials where 80% were incongruent and 20% were congruent.

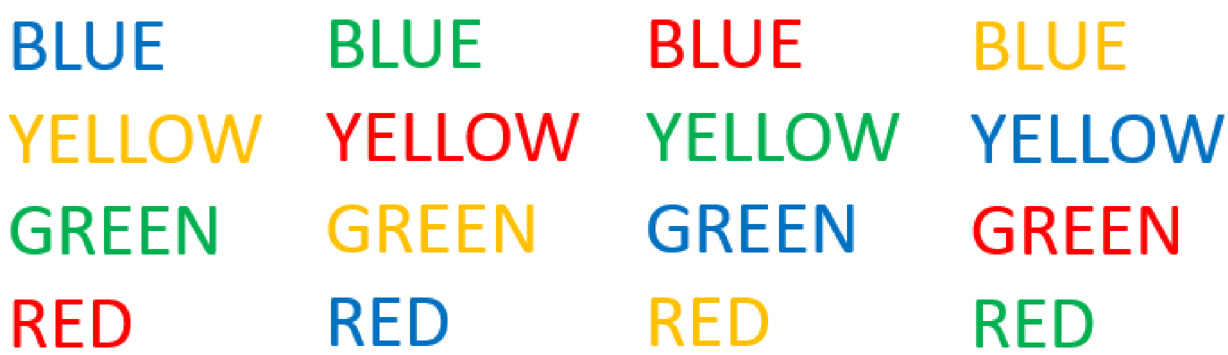
For all trials, the participant was instructed to focus their attention on a fixation cross in the center of the screen (see Figure 1). The inter-stimulus interval between the presentation of the fixation cross and the arrows was varied between 250ms, 500ms, and 750ms. Participants were instructed to press a key on the response pad to designate the direction of the center arrow (left or right) within each block of trials. Four reaction time (RT) averages were calculated for each participant: 1) average RT for congruent trials completed correctly, 2) average RT for congruent trials completed incorrectly, 3) average RT for incongruent trials completed correctly, and 4) average RT for incongruent trials completed incorrectly. In addition, accuracy was calculated for congruent trials and incongruent trials for each participant.



Note. This is an example of a fixation cross, congruent arrows, and incongruent arrows.

Figure 1 Flanker Task Example

Stroop Task. Next, the participants completed a computerized Color-Word Stroop task (Stroop, 1935). The Stroop task included a series of color words in differing font colors to assess the participants' ability to inhibit the routine behavior to read and respond to the meaning of the word instead of the font color of the word. The Stroop task included a variety of congruent and incongruent colored word pairings. An example of a congruent trial is the word "RED" appearing in red font color (see Figure 2). However, if the word "RED" is presented on the screen in the font color blue, this is an incongruent trial because the font color does not match the meaning of the word presented (see Figure 2). Each trial presented one of the following words: "RED," "BLUE," "GREEN," or, "YELLOW" and the font colors included red, blue, green, or yellow. The participants were instructed to press a key that corresponded with the font color of the word. In the previous example, if the word "RED" is presented in the font color blue, the participant must press the blue key on the response pad to be counted as correct. A total of three blocks were presented to the participant – one practice block followed by two experimental blocks that were counterbalanced between participants. All participants first engaged with a practice block with a total of 48 trials (40 congruent, 8 incongruent). Next, the MC block consisted of 110 trials where 80% were congruent while the MI block consisted of 110 trials where 80% were incongruent. Four RT averages were calculated for each participant: 1) average RT for congruent trials completed correctly, 2) average RT for congruent trials completed incorrectly, 3) average RT for incongruent trials completed correctly, and 4) average RT for incongruent trials completed incorrectly. In addition, accuracy was calculated for congruent trials and incongruent trials for each participant.



Note. The column on the left represents congruent color word parings.

Figure 2 Color-Word Stroop Task Example

Simulation Condition

Before the participants completed the baseline concussion assessment, they were randomly assigned to a simulation (sandbagging) or control condition. Participants in the control condition read a vignette which encouraged the participants to perform their best during the following assessments. The vignette stated:

> "You are a senior in high school who has played football all your life. This season of football is particularly important because college recruiters are coming to see you play and you have the chance of being awarded a full ride to one of your top colleges. The key is that you stay healthy all season for the recruiters to watch you play. Before the season

starts, you know that everyone takes a baseline assessment for concussions. You decide to give your best effort on these baseline measures to avoid any unintentional damage to your brain through multiple concussions. You want your coaches to be able to detect if a concussion occurred. This will ensure that you are still able to play football."

Participants who were assigned to the sandbagging condition were presented with a vignette to set the scene as to why they are being asked to give poor performance, sandbag, on the assessment. This vignette stated:

> "You are a senior in high school who has played football all your life. This season of football is particularly important because college recruiters are coming to see you play and you have the chance of being awarded a full ride to one of your top colleges. The key is that you stay healthy all season for the recruiters to watch you play. Before the season starts, you know that everyone takes a baseline assessment for concussions. You do some research to find out that the baseline test is used to detect concussions post-injury and if your post-injury score is below your baseline, you will be benched for the season. So, you figure, if you do just poorly enough on the baseline assessment, and if you suffer a concussion during this season, it will likely go undetected, and you will not get benched for the season. You also must avoid being caught by the effort indicators. If you 'trip' one of the effort indicators, you will be caught and have to take the assessment again."

No additional details pertaining to typical post-injury behaviors, symptoms, or recovery were given to the participants. Clarifying questions were asked to all participants as an attention check to verify the instructions. Specifically, participants were asked to restate the paragraph in their own words, describe their method(s) to perform at their best or sandbag performance, and the researcher emphasized the importance of following the instructions associated with their condition assignment on the subsequent assessment.

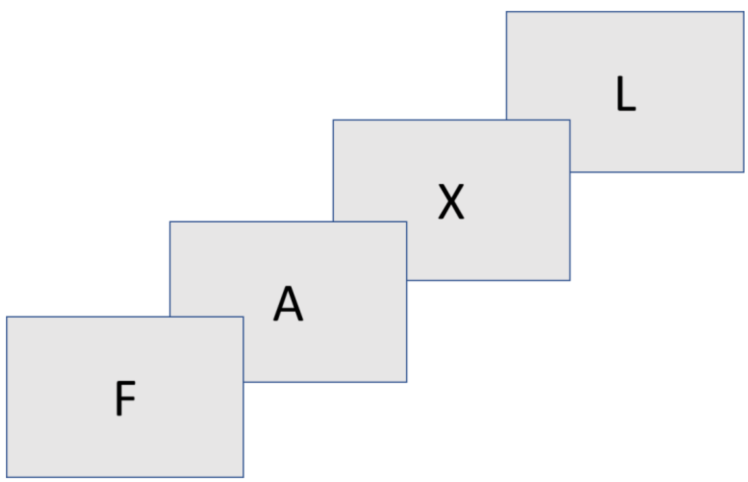
SportGait

The SportGait app, as described by Lecci and colleagues (2020), was used as the concussion baseline measure. The SportGait app is a self-guided baseline screener that includes a symptom checklist, an abbreviated Conners' Continuous Performance Test (CPT-3), and a gait assessment. Within SportGait, participants were first presented with a medical information page which asked demographic questions (i.e., age, sex, concussion history, and ADHD diagnosis). For example, questions about concussion history were asked through open-ended questions ("previous number of concussions," and "longest symptom duration").

Next, the symptom checklist included questions pertaining to the participant's concussion symptoms and the severity of the symptoms. The participants endorsed any current symptom which fall in four different categories: physical (e.g., headache, nausea, dizziness, and visual problems), cognitive (e.g., feeling mentally foggy, and/or difficulty concentrating), emotional (e.g., irritability, sadness, and/or nervousness), and sleep (e.g., drowsiness, and/or sleeping more than usual). Each of the categories were measured with a Likert scale of 0 (none) to 6 (severe). All the questions were pre-answered with 0 (none) and the participant was instructed to change the answer to reflect the severity of any symptom(s) they had. This symptom endorsement data is reported as total number of symptoms and total severity. There was a total of 22 possible symptoms with total possible severity of 132.

Next, the CPT-3 required eight minutes of sustained attention to respond to a series of letter stimuli (Lecci et al., 2021). During this portion of the task participants were asked to respond by tapping the phone screen as quickly and as accurately as possible to all letters presented on the screen except for the letter ‘X’. When the participants saw the letter ‘X’ they were instructed to withhold a response and to simply wait for the next letter to appear. A total of 180 trials (three blocks of 60 trials) were presented.

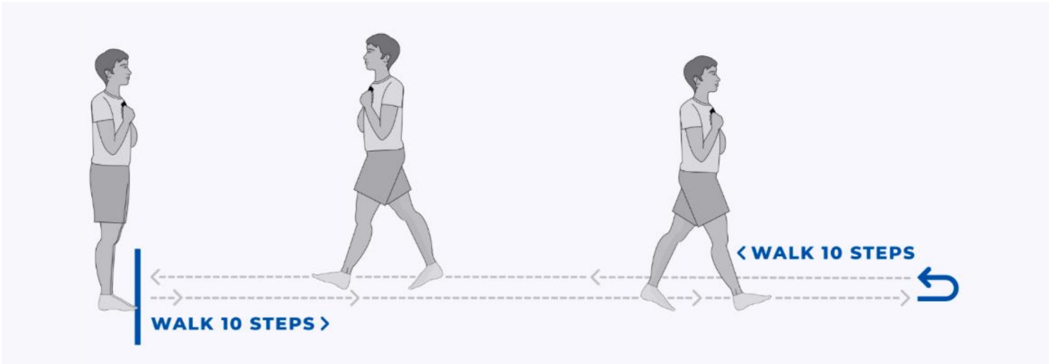
The CPT-3 is scored on three primary indicators and five secondary indicators. For the purpose of this study, I focused on the three primary indicators: hit reaction time (HRT, the average amount of time a participant needed to accurately respond to a trial), omissions (no response to a targets letter [e.g., A, M, T]; see Figure 3), and the hit reaction time variability (lower scores indicate consistency while higher scores indicate a lack of stamina or more variability). All results from the CPT-3 were standardized to normative data from SportGait.



Note. Participants must respond to all letters except for the letter ‘X’.

Figure 3 Conners’ Continuous Performance Task (CPT-3) Example

Lastly, the participants completed a gait assessment which measured the participant’s symmetry, stability, stride, and power while walking. For this portion of the assessment participants held the mobile device with the SportGait app securely to the center of their chest. The app uses hardware within the device to detect changes in posture, gait, and speed of movement. The participants were asked to walk ten steps, turn around, and walk ten steps back to their starting position. Participants were asked to walk as if they are walking to the grocery store. The participants pressed “START” on the app screen before they took their first step. When the participant reached the tenth step, turned around, and walked back to their starting position, then participants pressed “STOP” on the app screen. The participants repeated the walking tasks two more times for a total of three walking trials, walking ten steps twice per trial (see Figure 4).



Note. Credit for this photo belongs to SportGait App

Figure 4 Gait Assessment – SportGait App Visual Instruction

SportGait computed power, stride, stability, and symmetry. Power was measured with five indicators (striking force, pushing force, forward power, vertical power, and side power). Stride was measured with four indicators (stride time, stance phase, swing phase, and double stance). Stability was measured with two indicators (support variability and gait smoothness).

Finally, symmetry was measured with three indicators (forward sway symmetry, side sway symmetry, and side-to-side symmetry). Due to the large amount of data within the gait assessment, I focused on stride time, stride power, side to side movement symmetry, and gait smoothness for my analyses. Stride time reflects the average time to complete a full gait cycle, where higher scores indicate slower walking speed. Stride power indicates the participant's efficiency in movement, with a lower score meaning less energy, coordination, and efficiency in their walking. Side to side movement reflects sway of the trunk from left to right with higher scores indicating greater instability. Lastly, gait smoothness measures the body's movements, with lower scores expressing reduced body rhythm (overall movement) while walking. These four outcomes focused primarily on the nuances of the gait generally. All gait assessment output were standardized to normative data from SportGait. In all, the SportGait assessment required about 20 minutes to complete.

Qualitative and Quantitative Post-Assessment Interview

At the end of the SportGait protocol, all participants were asked to respond to a series of open- and close-ended questions about their performance. The participants in the sandbagging condition responded to questions that were focused on the strategies used to fake poor ability. Participants in the control condition responded to questions on the strategies used to give their best effort. Specifically, the individuals in the sandbagging condition were asked to reflect on their thoughts and behaviors during the baseline assessment, what types of behaviors they were expressing to sandbag and what they did to make these behaviors believable. The participants were encouraged to describe their thought process during the SportGait assessments to determine how participants actively attempted to fake baseline assessments. Participants rated their level of effort on a 1 (no effort) to 7 (full effort) Likert scale for each task completed (Flanker, Stroop, CPT-3, and Gait). The level of effort applies to both the sandbagging and control condition. Once the participant completed the closing survey, they were thanked, debriefed and awarded SONA credit and a $5 monetary incentive for participating.

CHAPTER III

RESULTS

SportGait Performance Differences by Condition

My first research question focused on determining group differences between the control group and the sandbagging group on SportGait performance. Specifically, I hypothesized that individuals who were assigned to sandbag would endorse more concussion symptoms and report higher severity. I also expected that they would have longer HRTs, make more errors (omissions), and be more variable in their reaction times overall on the CPT-3. Finally, I hypothesized that sandbagging participants would differ from control participants on the gait indicators (stride time, stride power, side to side movement, and gait smoothness).

In Table 1 below, the means, standard deviations, and standard errors are presented for the sandbagging and control groups on each of the dependent variables that were examined.

Table 1 Overall SportGait Performance Based on Group Assignment

SportGait Assessment	Control			Sandbag		
	M	SD	SE	M	SD	SE
Symptom Endorsement	4.77	6.28	1.34	22.55	7.76	1.65
Symptom Severity	10.9	19.4	4.14	59.5	38.31	8.17
HRT	-0.62	7.27	1.58	18.23	19.89	4.24
Omissions	1.32	13.68	2.92	20.18	20.72	4.42
Hit Variability	-0.76	12.48	2.72	21.18	16.02	3.42
Stride Time	-0.57	11.57	2.52	4.18	36.59	7.78
Stride Power	-1.19	7.74	1.69	-7.18	8.38	1.79
Side to Side Movement	12.19	3.36	0.73	13.42	3.69	0.85
Gait Smoothness	7.57	12.03	2.63	3.05	15.62	3.33

Symptom Validity Assessment

Individuals in the sandbag group, on average, endorsed a greater number of symptoms $t(42) = 8.35$, $p < .001$, $d = -2.83$. The sandbag group also stated symptoms were occurring at a greater severity than the control group, $t(31.10) = 5.37$, $p < .001$, $d = -2.55$. For these tests, Levene's test for equality of variance was significant, meaning equal variances of the data cannot be assumed. Therefore, the adjusted degrees of freedom are reported. On the surface, it appears that the mean differences between groups were very substantial but in comparison to the possible range of scores (0-22 for number of symptoms and 0-132 for severity of symptoms) the differences are relatively small, but statistically significant. As such, the group differences suggest that individuals who were instructed to sandbag endorsed more concussion related symptoms at a mild to moderate severity when compared to the control group (see Table 1). In other words, sandbaggers' performance was exaggerated enough to be considered poorer than average but not so substantially that their behaviors would trigger additional scrutiny.

Conners' Continuous Performance Task-3 (CPT-3)

When a participant scored either significantly above or below the normative mean on any of the SportGait assessments that observation was recorded as a concussion indicator. Overall, the results of this study suggest that those in the sandbagging condition demonstrated a greater number of primary concussion indicators (HRT, omissions, and hit reaction time variability) from the CPT-3 (see Table 2).

Table 2 CPT-3 Indicators

	Condition	
Number of Indicators	Control	Sandbag
0	15	6
1	5	3
2	1	3
3	1	10

A series of independent samples *t*-tests was used to determine the difference in performance on the CPT-3 for sandbag and control participants. Sandbaggers demonstrated significantly slower HRT than those in the control group, $t(26.73) = 4.16$, $p < .001$, $d = -2.59$. Additionally, sandbaggers produced more omission errors when compared to the control group, *t*(36.39) = 3.56, *p* = .001, *d* = -1.38. Lastly, sandbaggers had greater variability of their response speed compared to the control group, *t*(39.45) = 5.02, *p* < .001, *d* = -1.76. Overall, the sandbag group performance was slower, less accurate, and demonstrated greater variability in response speed (see Figure 5).

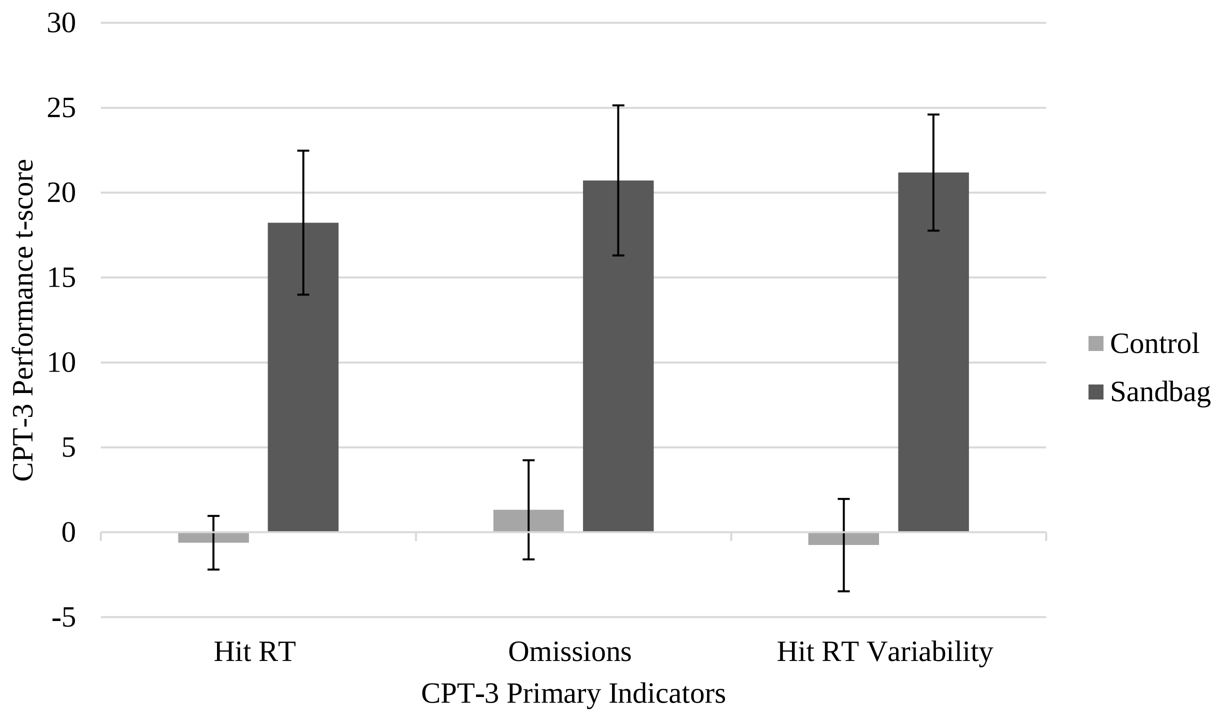


Figure 5 Average Performance on CPT-3 Based on Condition

Gait

For the gait assessment, I analyzed stride time, stride power, side to side movement, and gait smoothness. When a participant scored either significantly above or below the normative mean on any of the gait indicators that observation was recorded as a performance indicator (see

Table 3). Sandbaggers had a greater number of indicators that fell outside of the mean for more categories within each outcome group. In other words, sandbaggers' performance was different than the average performance on the gait assessment.

Table 3 Gait Indicators

		Condition	
	Number of Indicators	Control	Sandbag
Stride			
	0	11	6
	1	3	3
	2	1	0
	3	4	4
	4	2	9
Power			
	0	7	3
	1	5	7
	2	6	5
	3	0	2
	4	1	4
	5	2	1
Symmetry			
	0	0	0
	1	0	0
	2	5	3
	3	16	16

A series of independent samples *t*-tests was performed to determine the differences between the control group and sandbag group on the indicators from the gait assessment. First, while the sandbag group was slower to complete the walking task compared to the control group, the two groups were not significantly different from one another $t(41) = 0.57$, $p = .57$, $d = -.41$. However, the two groups did significantly differ with respect to stride power, $t(41) = 2.43$, $p =$

.02, *d* = .77 (see Figure 6). As for side to side movement, the sandbag group was not different from the control group, *t*(41) = 1.11, *p* = .28, *d* = -.37, which means that the two groups did not differ in left to right trunk movement, which suggests consistent symmetry while walking. Similarly, the sandbag group was not different from the control group in overall gait smoothness, *t*(41) = 1.06, *p* = .29, *d* = .38. Therefore, all participants demonstrated commensurate rhythmic body movements and efficiency during the walking task (see Figure 6).

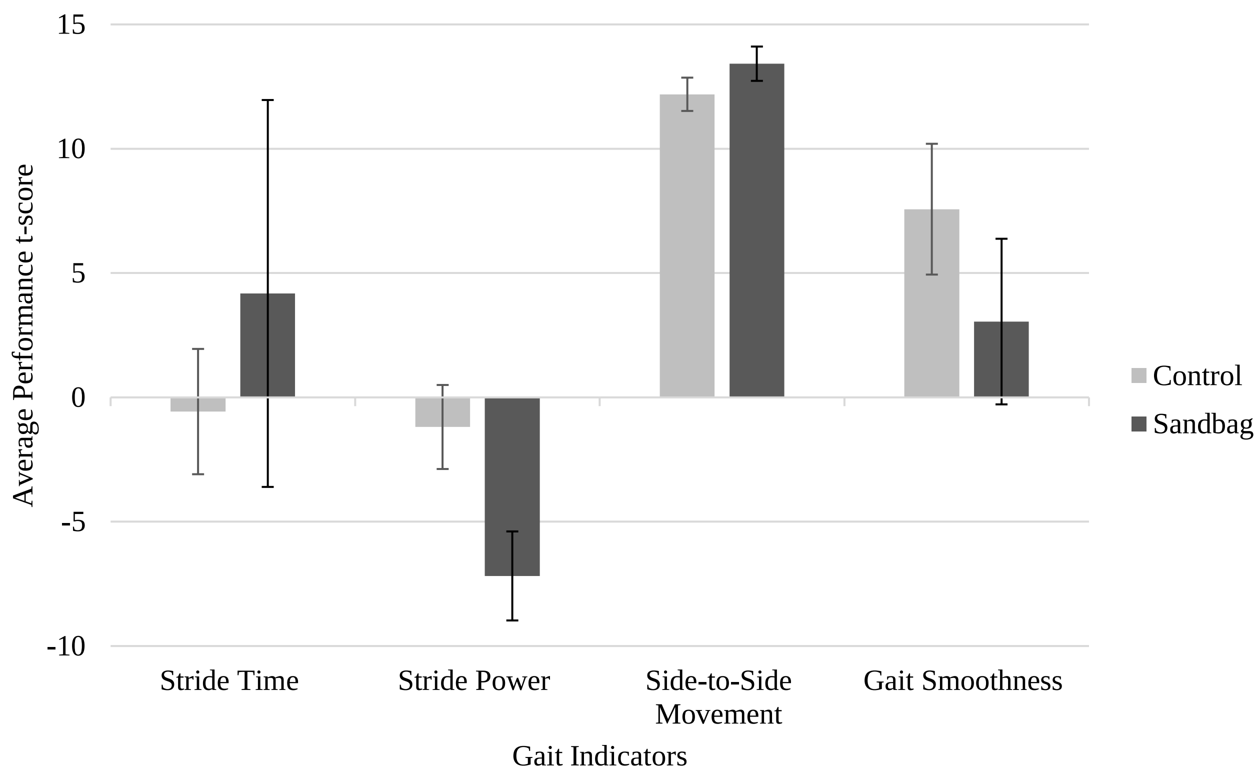


Figure 6 Average Performance on Gait Assessment Based on Condition

The Impact of Cognitive Control Within the Sandbag Group

In addition to assessing group difference on the SportGait assessments, I aimed to determine if cognitive control ability was related to effectiveness and consistency of sandbagging performance. Specifically, I hypothesized that participants with greater cognitive control, as measured by performance on the Flanker and Stroop tasks, would be more successful sandbaggers than those who are lower in cognitive control. The dependent variables from SportGait that I examined were CPT-3 outcomes (HRT, omissions, and hit reaction time variability) and gait outcomes (stride time, stride power, side to side movement, and gait smoothness).

Stroop performance within the participants who would later be assigned to the sandbag condition mirrored typical Stroop behavior (Stroop, 1935). Notably, within the mostly congruent block participants were more accurate on congruent trials (*M* = .98, *SE* = .004) than incongruent trials (*M* = .96, *SE* = .005), *t*(21) = 2.27, *p* = .03 (see Figure 7).

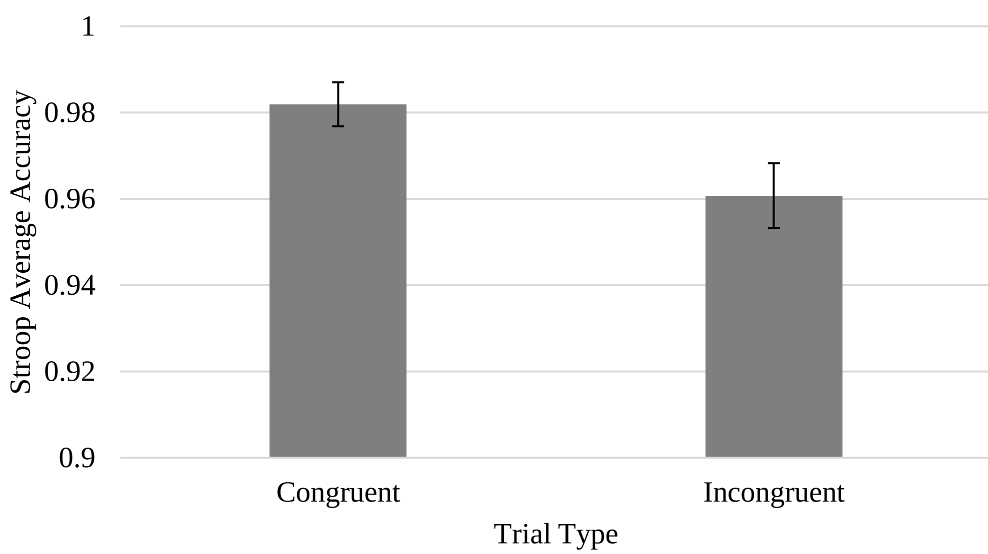


Figure 7 Stroop Accuracy for Sandbag Group

Reaction time for congruent and incongruent trials was also examined. When participants responded to congruent trials correctly (*M* = 922.15, *SD* = 104.74) they did so faster than when they responded to incongruent trials correctly (*M* = 1136.14, *SD* = 188.87). When participants made an error, they were faster on congruent trials (*M* = 882.86, *SD* = 104.27) than incongruent trials (*M* = 1130.00, *SD* = 250.13). A repeated measures ANOVA revealed a main effect of congruency, F (1,7) = 16.52, p = .005, η^2 = .70, however, there was not a significant difference between trials completed accurately or not, F(1,7) = .41, p = .54, η^2 = .06. Also, there was no significant interaction, F(1,7) = .23, p = .65, η^2 = .03. Of note, however, is that only eight participants had trial errors. Fourteen participants were able to complete every trial within the Stroop task with 100% accuracy, therefore those fourteen people did not have any error reaction times to examine with the ANOVA (see Figure 8).

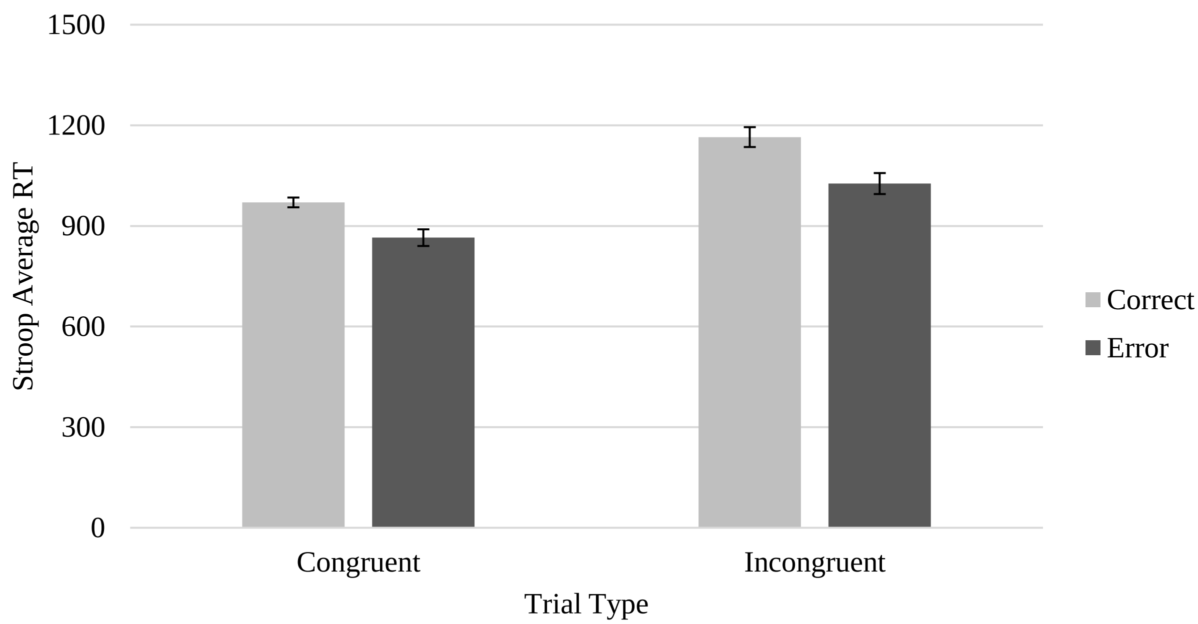


Figure 8 Stroop Reaction Time for Sandbag Group

As an additional measure of cognitive control, the participants completed the Flanker task. However, the results of the Flanker were not as expected (Eriksen & Eriksen, 1974). First, five of the 22 participants who were eventually assigned to the sandbag condition responded incorrectly to most or all incongruent trials. Their performance on the Stroop Task was within normal range which may suggest that these participants were particularly inattentive to the Flanker instructions or that they lacked a sufficient understanding of the task. After those five participants were removed from Flanker analysis, the results were consistent with typical Flanker findings. Indeed, they revealed a significant difference in accuracy between congruent and incongruent trials, $t(16) = 2.08$ $p = .05$. Specifically, there was higher accuracy for congruent trials ($M = .97$, $SD = .05$) and lower accuracy for incongruent trials ($M = .83$, $SD = .28$; see Figure 9).

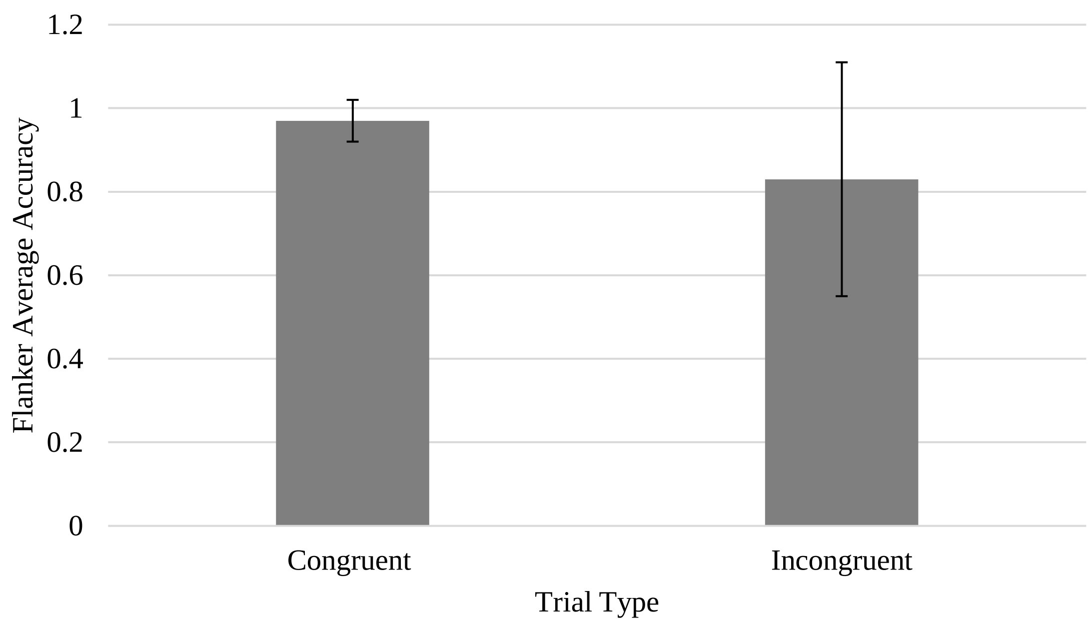


Figure 9 Flanker Accuracy for Sandbag Group

As for reaction time on the Flanker task, participants responded faster to congruent trials ($M = 1065.20$, $SD = 91.85$) and slower for incongruent trials ($M = 1277.06$, $SD = 259.75$; see Figure 10). A repeated measures ANOVA revealed a main effect for accuracy, $F(1,8) = 13.38$, p

= .006, η^2 = .63, but not congruency, $F(1,8)$ = .001, p = .97, η^2 = .00, nor the interaction, $F(1,8)$ = .27, p = .62, η^2 = .03. However, as was noted for the Stroop task, only nine participants made errors and had error reaction times. Because there were so many outlier participants and there was not a typical effect of congruency, Flanker task performance was not used as an indicator of cognitive control for subsequent analyses.

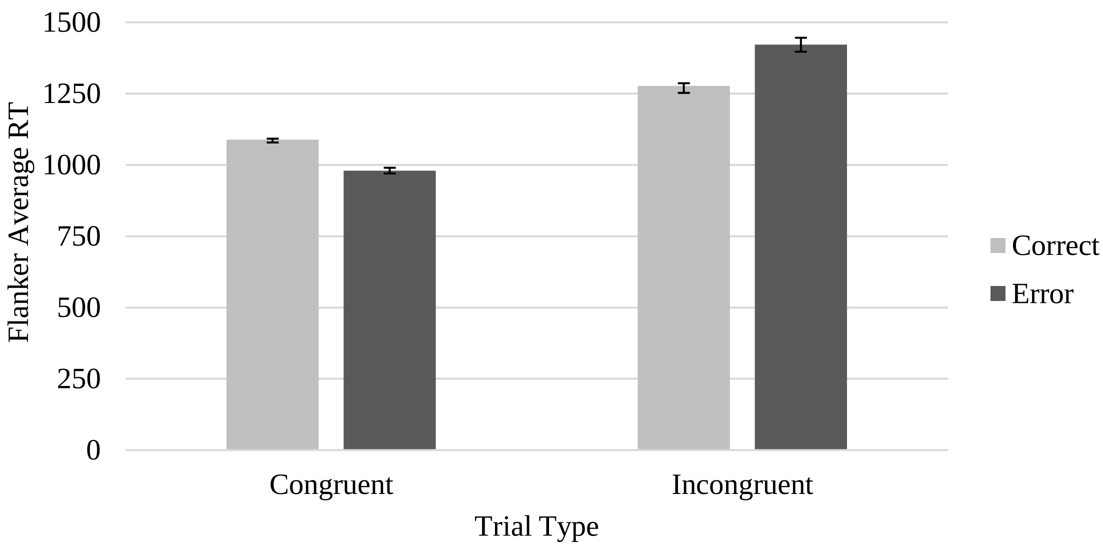


Figure 10 Flanker Reaction Time for Sandbag Group

Conners Continuous Performance Task- 3 (CPT-3) and Cognitive Control

To determine if cognitive control is related to sandbagging performance on the CPT-3, a series of linear regressions were used to predict HRT, omissions, and hit reaction time variability. To generate the cognitive control predictor, I calculated the difference between reaction time for correctly completed congruent trials and the reaction time for correctly completed incongruent trials (RTCongruentCorrect – RTIncongruentCorrect). The goal here was to indicate how much participants slowed down when they needed to resolve a response conflict (an incongruent trial). I reasoned that greater cognitive control would be indicated by less slowing, or less time needed to resolve the response conflict without producing an error. With this independent variable, cognitive control did not significantly predict HRT, *B* = -.01, *t*(21) = 0.43, *p* = .67, *95% CI B* [-.070,-.096], omissions, *B* = -.02, *t*(21) = 0.58, *p* = .57, *95% CI B* [-.08, .04], or hit reaction time variability, *B* = .02, *t*(21) = 0.74, *p* = .47, *95% CI B* [-.06, .03].

Gait Assessment and Cognitive Control

For the gait assessment, a series of linear regressions was used to determine if cognitive control, using the computed independent variable described above, predicted gait (stride time, stride power, side to side movement, and gait smoothness). Cognitive control did not predict stride time, *B* = .02, *t*(21) = .40, *p* = .70, *95% CI B* [-.09, .13], stride power, *B* = -.004, *t*(21) = .31, *p* = .76, *95% CI B* [-.06, .03], side to side movement, *B* = .001, *t*(21) = 0.18, *p* = .86, *95% CI B* [-.01, .01], nor gait smoothness *B* = .03, *t*(21) = 1.30, *p* = .21, *95% CI B* [-.02, .07].

CHAPTER IV

DISCUSSION

Cognitive-based baseline concussion assessments, like ImPACT, are useful for detecting concussions in sport. However, ImPACT has been criticized due to its low discriminant validity and the capacity for coaches and athletic trainers to direct athletes on how to ‘beat’ the assessment (Erdal, 2004; Schatz et al., 2017). An alternative baseline concussion assessment that may be more robust is SportGait (Lecci et al., 2020). SportGait includes a variety of cognitive and behavioral assessments to measure baseline performance. While it has been effectively used to detect concussions by comparing athletes’ baseline and post-injury performance, sandbagging of baseline performance has not been fully examined. Sandbagging is the effortful manipulation of behaviors to create inaccurate baseline scores with the goal of concealing a future head injury (Erdal, 2012; Gaudet & Weyandt, 2017; Schatz et al., 2017). One of the goals of this study was to determine whether performance differences would be observed on the assessments within SportGait when a participant is instructed to sandbag versus when a participant is encouraged to put forth their best effort.

Those who sandbag may need to utilize greater cognitive control to sustain their purposefully poor performance. Cognitive control involves controlling behaviors to match a desired goal (Nigg, 2017). Greater cognitive control is required when faced with a situation where one must resolve a conflict. For example, cognitive control is necessary in the Stroop and Flanker tasks to resolve a response conflict during incongruent trials. People who demonstrate strong cognitive control on those tasks are able to inhibit learned behaviors (reading the word or following the direction of the flanking arrows), and thereby achieve higher accuracy scores and faster reaction times.

Past research has not examined whether individual differences in cognitive control affect athlete's ability to sandbag performance. Therefore, the second goal of this study was to determine if cognitive control, as measured by response time slowing on the Stroop task, predicted sandbagging performance on the CPT-3's primary indicators and the gait indicators.

Sandbagging SportGait

The results of this study indicated that individuals who were instructed to sandbag differed from normative performance much more often than individuals who were instructed to put forth their best effort. However, this pattern was not observed on all of the SportGait outcomes. While sandbagging participants subjectively endorsed more symptoms, and objectively demonstrated worse performance on the CPT-3, as measured by HRT, omissions, and response time variability, they did not consistently demonstrate gait differences when compared to the control group. When looking at individual participant's performance compared to normative data, their symptom endorsement stayed within the mild to moderate severity range. This indication alone does not suggest a probable concussion and should be considered alongside the CPT-3 and gait assessments. When the symptoms are compared to only to the CPT-3 performance, there is consistency within symptom reporting and overall CPT-3 performance. This would be indicative of concussion-like symptoms. However, when both the symptom evaluation and CPT-3 performance is compared to gait, there is no longer this consistency, suggesting poor performance on the previous assessments instead of concussion related symptoms.

Given this pattern of performance, if the sandbagging participants were to return for testing after an actual concussion, it is likely that their performance would not be flagged as concerning if only the symptom questionnaire and CPT-3 were examined. This would mean that a concussed athlete would likely be permitted to return to play. Fortunately, SportGait's inclusion of the gait assessment, which is not included in any form within ImPACT, appears to be more robust to sandbagging attempts. This suggests that objectively impaired gait may be difficult to produce, at least without coaching. Therefore, while 35% of participants successfully sandbagged on ImPACT (Gaudet & Weyandt, 2017), the inclusion of objective gait assessment within SportGait may render it more resistant to sandbagging.

Cognitive Control and Sandbagging SportGait

In addition to examining group differences on SportGait, I wanted to determine if cognitive control was a predictor of successful sandbag behavior. All participants' cognitive control was measured before their group assignment (sandbag or control group). Overall, while most participants appear to have traded speed for accuracy on the Stroop, their performance indicated that they were more accurate and faster to respond to congruent trials and less accurate and slower to respond to incongruent trials. While this pattern was also observed for the Flanker task, there were several participants who may not have understood the instructions. Even after removing those participants as outliers, I determined not to use data from the Flanker to test my second hypothesis.

Using only Stroop task performance as an indicator, a series of regressions were used to determine if cognitive control would predict sandbagging performance on the objective SportGait outcomes (HRT, omissions, hit reaction time variability, stride time, stride power, side to side movement, and gait smoothness). The results of these regressions did not support my hypothesis. Cognitive control, as measured by the response time cost for resolving the conflict of incongruent trials in comparison to congruent trials (where no conflict exists), did not predict HRT, omissions, or response time variability on the CPT-3. Further, none of the regression models significantly predicted stride time, stride power, side to side movement, or gait smoothness.

While this second hypothesis was not supported, the results for the first hypothesis indicate that sandbagging on the SportGait assessment is most obvious on the subjective measures of symptom endorsement and severity, less obvious and yet still detectable on the CPT-3, but very difficult on the gait portion of the test. Specifically, participants reported exaggerating specific symptoms that are related to concussions by trying to "fake low levels of some problematic signs that might point to a concussion." Other participants discussed strategies of performance on the CPT-3 like, not responding to the letters as fast or "I sometimes clicked after the X on purpose or I did not click after another letter on purpose."

The findings of this study coincide with Erdal (2012). Erdal described that their participants endorsed more natural errors than calculated errors when completing cognitive assessments. These natural errors included changes in response times to create errors more naturally. Notably, a similar pattern of performance was observed in this study. Indeed, participant reported using slower reaction times and they "emulated what my responses would be if I was very tired and skipped a few of the X's to show that I didn't process all of them."

Further, participants may have had difficulty determining the line of ‘normal’ gait performance and poor gait performance. Indeed, individuals instructed to sandbag had greatest difficulty sandbagging their gait, perhaps due to the nuances associated with how gait is measured and effects individuals with concussions. Concussions cause slower walking speeds, shorter strides, greater need for stability while walking (keeping two feet on the ground more frequently) and more nuanced trunk movements while walking (Guskiewicz, 2003; Howell et al., 2018). These symptoms of concussion may not have been known to the participants and instead, the participants “messed up” their natural walk by over or under exaggerating different aspects of their gait, instead of mimicking concussion symptoms. For example, participants reported trying to “simulate a worse sense of balance” by implementing poor coordination, instability, walking in curve pattern, or “act[ing] sluggish.” The participants’ choice of behaviors to produce could be due to lack of knowledge of concussion symptoms and how concussion behaviors are presented in tasks like the gait assessment.

Overall, participants reported feeling uneasy about sandbagging. One participant reported, “honestly, I have an issue with not trying my best to complete anything to the best of my ability…” and another participant reported difficulty “getting into the mindset of someone trying to lie…” Participants reported more mild severity for concussion symptoms, changes in reaction time for the CPT-3, and purposeful changes in stride time on the gait assessment. Athletic trainers and coaches should take into consideration how performance across all assessments is related instead of examining only the cognitive assessment (Howell et al., 2018). This may lead to stronger baseline assessment scores and more accurate concussion detection.

Limitations and Future Directions

While I measured cognitive control ability with the Stroop and Flanker tasks, I was not able to measure general cognitive ability. Due to the COVID-19 pandemic, many students did not have to take standardized tests (e.g., ACT or GRE) as an entrance criterion for college. Moreover, while I could have requested high school grade point average for my participants, I was concerned that it may have been unduly influenced by the pandemic and may not have been a stable measure of their cognitive abilities due to outside stress, school closures, or online learning difficulties. A measure of general cognitive ability could have added a level of control between all participants. Future research should consider general cognitive ability and cognitive control ability on sandbagging performance.

Additionally, a greater number of participants and more from various demographics would be helpful in trying to generalize the results of this study to increase power. More participants are needed to account for outliers who were removed from the Flanker analysis. Further, this sample included mostly females. Considering that males may be more likely to trade accuracy for speed (Roebuck-Spencer et al., 2008), recruiting a larger sample of males for this study would have been beneficial. This sample is not representative of the number of males and females playing college or professional contact sports. Notably, performance on the Stroop and Flanker tasks was characterized by high accuracy. This impacted my ability to examine differences in response times between trials completed correctly and incorrectly and restricted the ways in which I could examine cognitive control as a predictor of sandbagging performance.

Anecdotally, many students reported being familiar with the Stroop task or similar puzzles. For example, a new game on social media is called the “Color Blind Test.” It is essentially a Stroop task where a color word is presented in congruent or incongruent font colors, however, the viewer must choose between two options (the word or the font color). This exposure may be one reason why participants responded at ceiling for the Stroop task measuring cognitive control. Familiarity with or practice effects of the Stroop task may have limited the variability of accuracy seen in this study.

Future research should examine coaching behaviors of concussion assessments. This study allowed the participants to decide what behaviors to endorse to simulate poor performance. Future researchers should include coaching strategies (e.g., provide a list of symptoms or show the participant how to mimic concussions) to teach their participants how to change their performance on a concussion baseline assessment. Coaching performance should then be compared to a control group and a free reign group to determine if coaching influences sandbagging ability.

Additionally, future research should examine the difference between natural and calculated error strategies of sandbagging. Previous research stated that individuals who used more natural strategies (what felt right, not exact moment changes) were better able to simulate poor performance (Erdal, 2012). When participants in this study were instructed to sandbag, they were given creative freedom to simulate a low performance. In this case, participants likely used a calculated strategy during the subjective symptom assessment (e.g., over exaggerating or add one point to what a symptom would normally feel like). However, the CPT-3 allows an opportunity for participants to create calculated and naturally facilitated errors. For example, participants using the calculated strategy may predetermine and miss every n^{th} trial, whereas participants creating natural errors may occasional double tap the screen or slow responses to target items. This occasional change in response speed, likely creates natural errors without overly exaggerating reaction time or structured errors. Evidence of natural errors were included within this study, however, an in-depth analysis of these behaviors in needed.

Conclusions

Overall, this study indicated that participants who were instructed to sandbag subjectively endorsed more symptoms, objectively demonstrated worse performance on the CPT-3, but did not consistently demonstrate gait differences when compared to the control group. This suggests that SportGait's inclusion of a gait assessment may make it more robust to sandbagging. Individual differences in cognitive control were measured but did not predict sandbaggers' performance on SportGait. Therefore, athletic trainers who use SportGait baseline assessments can detect sandbagging behavior through inconsistencies of symptom endorsement and cognition performance compared to the athletes' gait performance. By catching sandbagging performance on the baseline assessment, athletic trainers can prevent false negative post-injury scores by examining behavior and symptom consistency across all assessment modalities.

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APPENDIX A

IRB APPROVAL

THE UNIVERSITY OF TENNESSEE
CHATTANOOGA

Institutional Review Board
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TO: Melissa Materia **IRB # 21-115**
Kiara Baker, Saige Lowery, Kylie O'Grady, Bree Rust, Dr. Amanda Clark

FROM: David Deardorff, Interim Director of Research Integrity
Dr. Susan Davidson, IRB Committee Chair

DATE: 11/3/21

SUBJECT: IRB #21-115: Does Cognitive Control Affect Successful "Sandbagging" of Concussion Symptoms?

Thank you for submitting your application for research involving human subjects to The University of Tennessee at Chattanooga Institutional Review Board. Your proposal was evaluated in light of the federal regulations that govern the protection of human subjects and approved via the expedited review procedure authorized by 45 CFR 46.110 and 21 CFR 56.110.

You must include the following approval statement on research materials seen by participants and used in research reports:

> ***The Institutional Review Board of the University of Tennessee at Chattanooga (FWA00004149) has approved this research project # 21-115.***

Please keep in mind that all research must be conducted according to the proposal submitted to the UTC IRB. If changes to the approved protocol occur, a revised protocol must be reviewed and approved by the IRB before implementation. For any proposed changes in your research protocol, please submit an Application for Changes, Annual Review, or Project Termination/Completion form to the UTC IRB. Please bear in mind that significant changes could result in having to develop a new application for submission and approval. Your protocol will be automatically closed at the end of the proposed research period unless a change request application is submitted. No research may take place under a closed or expired protocol.

A goal of the IRB is to prevent negative occurrences during any research study. However, despite our best intent, unforeseen circumstances or events may arise during the research. If an unexpected situation or adverse event happens during your investigation, please notify the UTC IRB as soon as possible. Once notified, we will ask for a complete explanation of the event and your response. Other actions also may be required depending on the nature of the event.

APPENDIX B

DEMOGRAPHIC QUESTIONNAIRE

1. What gender do you identify as?
   - ☐ Male
   - ☐ Female
   - ☐ Prefer not to answer

2. What is your race?
   - ☐ Hispanic or Latino
   - ☐ American Indian or Alaska Native
   - ☐ Asian
   - ☐ Black or African American
   - ☐ Native Hawaiian or Other Pacific Islander
   - ☐ Caucasian or White
   - ☐ Multiracial
   - ☐ Other
   - ☐ Prefer not to say

3. Select your age
   - ☐ 18
   - ☐ 19
   - ☐ 20
   - ☐ 21
   - ☐ 22
   - ☐ 23
   - ☐ 24
   - ☐ 25
   - ☐ 26
   - ☐ 27
   - ☐ 28
   - ☐ 29
   - ☐ 30
   - ☐ 31
   - ☐ 32
   - ☐ 33
   - ☐ 34
   - ☐ 35
   - ☐ 36
   - ☐ 37
   - ☐ 38
   - ☐ 39
   - ☐ 40+

4. Did you play a high school sport?
   - ☐ Yes
   - ☐ No

5. If yes, what sport did you play? If no, type N/A

6. Do you play recreational sports? If yes, what sport?

7. Are you a UTC Club Sport Athlete?
   - ☐ Yes
   - ☐ No

8. What UTC Club Sport do you participate in?

APPENDIX C

DEBREIFING QUESTIONNAIRE FOR THE CONTROL GROUP

1. What strategy/strategies did you use to give your best effort on the SportGait assessment?

2. What were you thinking about during the SportGait assessment?

3. What behaviors did you do to show the experimenter you were giving your best effort?

4. Rate your effort on the following task

	1	2	3	4	5	6	7
Flanker Task (arrow direction)	❑	❑	❑	❑	❑	❑	❑
Stroop Task (color words)	❑	❑	❑	❑	❑	❑	❑

5. Rate your effort on the concussion assessment.

	1	1	3	4	5	6	7
SportGait Assessment - walking	❑	❑	❑	❑	❑	❑	❑
SportGait Assessment - sustained attention	❑	❑	❑	❑	❑	❑	❑

APPENDIX D

DEBREIFING QUESTIONNAIRE FOR THE SANDBAG GROUP

1. What strategy/strategies did you use to fake your behavior on the SportGait assessment?

2. What types of behaviors did you use to act as if you have a concussion?

3. What were you thinking about while faking concussion like behaviors on the SportGait assessment?

4. Were there any behaviors/reactions you had to inhibit (stop) from expressing?

5. Rate your effort on the following tasks.

	1	2	3	4	5	6	7
Flanker Task (arrow direction)	❑	❑	❑	❑	❑	❑	❑
Stroop Task (color words)	❑	❑	❑	❑	❑	❑	❑

6. Rate the effort you gave to fake your performance on the concussion assessment.

	1	2	3	4	5	6	7
SportGait Assessment - walking	❑	❑	❑	❑	❑	❑	❑
SportGait Assessment - sustained attention	❑	❑	❑	❑	❑	❑	❑

VITA

Melissa Ann Materia grew up in a small town in north New Jersey. She was born to Christine and Larry Materia and is the youngest of two children. The Materia family moved to a town outside of Memphis, Tennessee, which is where Melissa attended high school. Melissa started her college career at Chattanooga State Community College where she received her Associates of Science in Psychology in 2018. From there, she attended the University of Tennessee at Chattanooga to continue studying psychology. While at UTC, she was involved in multiple psychology research labs. Notably, a research experience in Dr. Amanda Clark's Assessing Cognition Lab was pivotal as it sparked her interest in cognitive and neuropsychology research. Melissa received her Bachelor of Science in Psychology in 2020. She continued her education in UTC's Masters of Science: Psychological Science program. Melissa worked in the Assessing Cognition Lab, Dr. Arnold's Substance Use and Mental Health Lab, and was a part of collaborative research projects with various psychology faculty members. She will graduate in May 2022, after which she will pursue a doctoral degree in Psychological Science. Melissa hopes to continue conducting research in the field of neuropsychology.