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VARIABILITY IN REACTION TIME AS A MEASURE OF MOTIVATION IN NEUROPSYCHOLOGICAL TESTING AT BASELINE

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ABSTRACT

Recent research has shed light on the gap in knowledge in understanding concussion as a form of traumatic brain injury (mTBI). Especially concerning is the significant prevalence of these injuries in athletics. As neuropsychological assessment has become an increasingly important part of return-to-play decisions, it is necessary that the results of testing be evaluated with the highest validity possible. Research has suggested that motivation can interfere with performance and requires consideration in interpretation of results. Variability has been suggested as a possible marker of test motivation in the context of concussion batteries. This study aimed to use variability in reaction time on a single test as a measure of motivation on baseline testing in a student athlete population at the collegiate level. Participants were divided into three motivation groups based on a subjective motivation measure: “Low”, “Moderate”, and “High”. The results of a multivariate analysis show a significant overall effect ($p = .034$) of motivation group on variability in reaction time such that lower motivation was associated with greater variability. This is important in considering the interpretation of neuropsychological testing data in a sports concussion context. If an individual is less motivated to perform well, their results will not accurately reflect their true cognitive functioning. Further, variability in performance may also be suggestive of variability in motivation. In this case, it would be important to consider how measures of acute motivation on tasks could help in the interpretation of testing outcomes. With more valid interpretations of an athlete’s relative functioning post-injury, we can make return-to-play decisions with greater confidence.

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Introduction

Increased interest in sports-related concussion has led to a large body of research devoted to identifying more effective techniques of assessment and management. The Centers for Disease Control and Prevention (CDC) has described concussion as a "silent epidemic" (Moore, Hillman, & Broglio, 2014), though increased research has helped bring the issue to public attention in the past decade. While this research has provided an abundant source of new information, it has also made clear the still overwhelming lack of knowledge on the topic.

Defining Concussion

Though the terms "mild traumatic brain injury" (mTBI) and "concussion" are frequently used interchangeably in the literature, several authors have noted the subtle, yet important, differences between the two. It has also been suggested that the use of the term "mild", along with "bell-ringer" and "getting dinged", creates an inappropriately weakened perception of the severity of concussion (Noble & Hesdorffer, 2013). Because the terms are not uniformly utilized, it makes defining them somewhat problematic. Thus, it is important to address the nuance. mTBI refers to a part of the traumatic brain injury (TBI) spectrum characterized by mild intracranial trauma (Dimou & Lagopoulos, 2014). Concussion, more specifically, refers to a pathophysiological process that involves the transmission of biomechanical forces to the brain, resulting in abnormal functioning that cannot be detected using traditional neuroimaging techniques (Weinberger, 2013).

While the presentation of concussion is highly heterogeneous across individuals, there are several common features. Post-concussion symptoms can be described in one of four categories:

physical, cognitive, affective, and somatic. Headache and dizziness are the most commonly reported symptoms, often seen soon after injury along with other physical and cognitive symptoms. Two trademark characteristics of concussion are confusion and amnesia (Weinberger, 2013). Only 10% of those who suffer concussions experience a loss of consciousness (LOC), though most will experience some level of transient amnesia. This amnesia can present itself as a loss of memory for the event that caused the injury, or often involves diminished recall for the events surrounding the trauma in the form of retrograde and anterograde amnesia. Although most of these symptoms are resolved within days or weeks after injury, research suggests that up to 30 percent of patients will experience prolonged symptoms that persist well beyond the normal recovery period (Dimou & Lagopoulos, 2014).

TBI is unique in that it affects individuals of all backgrounds. Peaks in occurrence are recognized in early childhood, adolescence, and in the geriatric population, with the highest peak in adolescence (Bruns & Hauser, 2003). While these injuries can occur as a result of accidents, falls, and combat, there has been heightened attention for the prevalence in sports-related settings, especially in adolescent and young adult populations.

Epidemiology

The current reported incidence of sports-related concussion (SRC) in the United States is 1.6-3.8 million, though it is noted that these numbers likely represent an underestimation due to underreporting of the injury (Weinberger, 2013). Underreporting may be a result of various factors, including a player's inability to recognize symptoms, or the player's active reluctance to be removed from play. It has been suggested that the actual rate of SRC may be as much as 10 times that of both moderate and severe traumatic brain injury (TBI) (Meaney & Smith, 2011), with a staggering $17 billion burden in direct and indirect cost in the United States annually (Moore et al., 2014).

Research of sports concussion has provided evidence of higher risk groups. Girls are reported to have a higher rate of concussion when compared to boys, which may be related to hormonal and behavioral influences, symptom reporting differences, musculature, and cerebral organization (Nelson, Janecek, & McCrea, 2013). SRC is reportedly highest in younger players, with a decreased risk in high school, and a subsequent increasing risk with progressing age and level. At the collegiate level, concussion represents 5.8% of all injuries seen in sports. This injury is reported across many sports, with cheerleading, lacrosse, and soccer representing some of the more high-risk sports. There is also a particularly elevated incidence reported among football players (Noble & Hesdorffer, 2013).

Due to the high contact nature of the sport, there is a significant amount of data on SRC from football populations. Interestingly, there is a reported 40% higher rate of concussion among players in Division II and Division III schools compared to Division I. This difference may reflect the extrinsic motivation from more competitive programs to diminish symptoms. Yearly concussion rates among NCAA players are estimated at 2.5 per 1000 competition athletic exposures and 0.4 per 1000 practice athletic exposures, with a single exposure representing participation in one competition or one practice, respectively (Noble & Hesdorffer, 2013). These repeated impacts may result in more subtle, subconcussive injuries that go unnoticed.

Pathology of Concussion

Pathophysiology.

Although concussion is considered a “mild” form of TBI, significant physiological changes occur after sustaining a concussive blow. Shearing forces are recognized as the principal mechanism of injury in concussion. These forces are caused by rotational motion and can result in deformed brain tissue (Meaney & Smith, 2011). Following such rotation, a neurometabolic cascade of events occurs that causes physiological changes in nervous tissue.

The membrane stretch that occurs at the neuronal axon causes voltage-gated potassium (K^+) channels to open, resulting in a membrane depolarization that induces the release of the excitatory neurotransmitter glutamate. The high K^+ efflux upon channel-opening overwhelms the glial cells, and they are not able to remove the excess concentration from the extracellular space (Giza & Hovda, 2001). This further exacerbates the membrane depolarization and subsequent glutamate release. Binding of glutamate to kainite receptors drives a surplus calcium influx into the mitochondria of the cells, causing mitochondrial swelling and dysfunction. These dysfunctional organelles then release reactive oxygen species (ROS) that cause oxidative stress and “irreversible modification of biologically important macromolecules” (Signoretti, Lazzarino, Tavazzi, & Vagnozzi, 2011). After the indiscriminate excitation, there occurs a diffuse neuronal suppression, which, as suggested by Giza & Hovda (2001), may be involved in the observable symptoms of early LOC and amnesia post-injury.

In order to restore membrane balance, the cell requires ATP to drive energy-requiring ion pumps. The immediate need for a large amount of ATP causes the cell to accelerate production through glycolysis—a less efficient, but faster mechanism of energy production (Giza & Hovda, 2001). Because the cell is working rapidly to overcome the ATP deficiency, it does not have the resources to spare for production of other substances, including *N*-acetylaspartate (NAA)—a suggested biomarker for brain damage. NAA deficits are seen in several neurological disorders, including concussion, and may be used as an indicator of continued dysfunction post-concussion (Signoretti et al., 2011).

Following injury, the local metabolism rate of glucose has been observed to increase by 46% above normal levels, an effect lasting 30 minutes to 4 hours (Signoretti et al., 2011). Subsequent to the increase in metabolism, there is a hypometabolic state during which there is up to 50% decrease in normal metabolic rates, reported to last 2 to 4 weeks (Giza & Hovda, 2001). The drastic decrease in metabolism causes an energy deficiency, and puts the brain in an energy crisis state. Signoretti et al. (2011) reported in an athlete population that metabolic disturbance was observed beyond the resolution of clinical symptoms, suggesting that this metabolic disturbance may be an important yet underappreciated aspect of complete recovery after concussion.

Structural and functional changes.

The definition of concussion states that it is an injury that lacks identifiable structural changes using traditional neuroimaging techniques. However, the use of higher sensitivity imaging techniques has allowed for detection of more microstructural changes.

Using traditional electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) techniques, a higher quantity of activated regions in the dorsolateral prefrontal cortex (DLPFC) has been observed in an adult mTBI population without clinical symptoms. Interestingly, this activation pattern seen in an adult population is not seen in a pediatric population that displays more overt cognitive dysfunction. This may suggest that such capacity for recruitment protects adults from more recognizable neurocognitive deficits in assessment

(Dimou & Lagopoulos, 2014). One study of high school football players using fMRI found that a subset of athletes who were not diagnosed with concussion, but received the most number of hits throughout the season had significantly reduced activation of the DLPFC and cerebellum (Talavage et al., 2014). The DLPFC is implicated in both of these to be vulnerable to subclinical effects of concussion, though adults may be more able to compensate than younger individuals. Advanced imaging techniques used in concussion research, including diffusion tensor imaging (DTI) and magnetic resonance spectroscopy (MRS), allow for visualization of even more subtle structural changes.

DTI uses the diffusion of water along axonal fibers as a measure of white matter integrity. This diffusion is assessed using two measures: anisotropic diffusion coefficient (ADC) and fractional anisotropy (FA). ADC measures the amount of diffusion, while FA measures the direction of diffusion. A healthy control would be expected to have lower ADC values and higher FA values, i.e. less unrestricted movement and more uniform directionality. DTI studies show abnormal diffusion in the splenium of the corpus callosum, internal capsule, and uncinated fasciculus of the inferior fronto-occipital, parietal and frontal subcortical white matter fibers of concussed populations (De Beaumont, Henry, & Gosselin, 2012; Dimou & Lagopoulos, 2014). A review by Collins et al. (2014) reported that while most researchers find an increase in ADC and decrease in FA in concussion populations, some have found a decrease in ADC and increase in FA in chronic phases post-injury. The exact implications of DTI data are not fully understood, but thus far appear to provide a promising component to concussion research.

MRS uses neurometabolites to assess the integrity of cell structures. Most concussion research has focused on levels of NAA, creatine, choline-containing compounds, and glutamate. This research has repeatedly shown reduced levels of NAA postconcussion (Signoretti et al., 2011; De Beaumont, 2012; Dimou & Lagopoulos, 2014). The DLPFC and primary motor cortex have been reported to maintain decreased levels up to 6 months after injury (Dimou &

Lagopoulos, 2014). This NAA deficit is not correlated with self-reported symptoms, suggesting that it may be useful in tracking persistent subclinical damage.

Neurocognitive effects.

Though the actual presentation of postconcussive cognitive deficits varies by individual, most patients do experience some form of cognitive difficulty during the course of their injury. The most sensitive cognitive functions affected, as noted by Nelson, Janecek, & McCrea (2013), are attention, concentration, processing speed, and memory. Within the first 24 hours post-injury, there are significant deficits in global functioning, memory acquisition, and delayed memory (Belanger & Vanderploeg, 2005). Moore et al. (2014) cited cognitive control, involving goal-oriented and inhibitory behavior, as being one domain especially sensitive to concussive effects. The most commonly damaged regions of white matter in concussed persons are those associated with cognitive control and memory function, suggesting that these two functions may be particularly vulnerable to the effects of injury.

While it has been previously suggested that these deficits are resolved along with other postconcussive sequelae, there is increased interest in cases of prolonged cognitive dysfunction in sports concussion. It has been suggested that between 10% (Noble & Hesdorffer, 2013) to 30% (Dimou & Lagopoulos, 2014) of concussed individuals experience a prolonged recovery period atypical of most. Acutely, this group is found to perform more poorly on cognitive tasks than both a typical recovery group and a control group (Nelson et al., 2013). This suggests that more severe cognitive deficits during a critical post-injury period may be predictive of recovery trajectory.

There is significant interest in the P3 event-related potential (ERP) component of EEG in regard to cognitive functioning in concussed populations. The P3 component is believed to represent stimulus classification and evaluation speed, distribution of attention to stimuli, and orienting attention to specific stimuli (Moore et al., 2014), and is frequently reported to show diminished activity in populations with a history of concussion compared to controls (Moore et al., 2014; De Beaumont et al., 2012; Gosselin et al., 2012). In studies of youth with a history of multiple concussions, the P3 reduction was significant several months after the most recent injury, and was more pronounced with a greater number of previous concussions (De Beaumont et al., 2012). This may be evidence that repeat concussions cause significant and additive effects.

Multiple concussions.

There is an increased interest in the possible consequences of repeat concussions, especially in the athlete population, because they may endure several collisions per competition or practice. One study of three NCAA football teams suggested that players sustain 400 or more impacts per season, though other recent estimates have suggested 520-1353 impacts per player per season (Crisco et al., 2011). Nelson, Janecek, & McCrea (2013) reported that 75-92% of repeat concussions occur within 7-10 days after the first injury. According to metabolic research, this acute post-injury period may represent an incredibly vulnerable phase of energy crisis during which the brain is attempting to re-establish homeostasis. If a second insult occurs, it could produce additive and detrimental effects reminiscent of a severe TBI (Dimou & Lagopoulos, 2014; Signoretti et al., 2011; Giza & Hovda, 2001).

Though the evidence is not entirely clear, multiple concussions have been suggested as having a role in the development of long-term deficits including depression, Alzheimer's disease, amyotrophic lateral sclerosis, and Chronic Traumatic Encephalopathy (Noble & Hesdorffer, 2013). With such alarmingly high rates of SRC, it is important that we understand how to best prevent, assess, and treat these injuries.

Evaluation of Concussion

Sideline Assessment.

When a player sustains a blow to the head during competition or practice, an acute assessment of functioning is generally administered on the sideline by an athletic trainer or other evaluator. This assessment includes checking mental status, motor ability, orientation, memory, and other postconcussion symptoms. There are two assessments that were developed and are utilized for this brief evaluation: the Standardized Assessment of Concussion (SAC) (McCrea et al., 1998) which measures general orientation, and the Sport Concussion Assessment Tool (SCAT3) (McCrory et al., 2013) which incorporates aspects of the SAC, along with more specific orientation questions and a test of balance. However, athletes often suffer from discrete cognitive and affective symptoms that are more difficult to detect from less sensitive sideline assessments.

Neuropsychological assessment of concussion.

Neuropsychological testing is increasingly considered a vital component of return-to-play (RTP) decisions for college athletes post-concussion. Current RTP guidelines, as set out at The 4th International Conference on Concussion in Sport, state that RTP should not occur on the day of injury. Players should return in a graded fashion, beginning with light activity and slowly increasing in moderation only if symptoms do not reappear (McCrory et al., 2013). Neuropsychological testing has been shown to reveal neurocognitive deficits even in patients who report no symptoms (Johnson, Kegel, & Collins, 2011). If an athlete returns to play before these symptoms have been resolved, there is a threat of negative consequences with a second injury including second impact syndrome, prolonged recovery after multiple injuries, and the cumulative effects of repetitive injuries (d'Hemecourt, 2011). These risks must be considered when making comprehensive RTP decisions.

Neuropsychological evaluations contribute to a decision on how and to what extent an athlete's functioning has been affected by an injury. One widely used model of assessment is that of pre- and post- injury comparisons. In this model, athletes complete baseline testing before participating in sports in order to assess their normal functioning. If they sustain a concussion, their post-injury scores are then compared to their baseline to determine the effects of the injury (Echemendia et al., 2013). Supporters of this intraindividual model claim that the baseline testing provides an accurate reference for evaluating post-injury functioning (d'Hemecourt, 2011; Johnson et al., 2011; Echemendia, Herring, & Bailes, 2009; McKeever & Schatz, 2003). In theory, this method accounts for differences between individuals. However, more recent research suggests that baseline testing may not be as necessary as previously thought (Arnett et al., 2014; Echemendia et al., 2013). Arnett et al. (2014) addresses the issues of the practice effect with multiple test administrations, as well as the fact that there is no empirical evidence suggesting that baseline references provide more accurate diagnoses. There are several confounding variables that make it difficult to determine the significance of neuropsychological testing results as they apply to each individual case.

The current literature points to motivation as an important consideration in interpreting test results. There are various ways of thinking about and assessing motivation. One frequently studied aspect of effort is that of malingering, or exaggeration of symptoms. Malingering is seen in cases in which the individual is motivated to perform poorly. An example of this cited in Bailey et al. (2006) is the finding that in individuals with mild head injury who were awaiting financial compensation, the most important variable affecting their recovery time was the time until settlement of their case. However, several studies (Inman & Berry, 2002; Binder, Kelly, Villanueva, & Winslow, 2003; Hubel, Yund, Herron, & Woods, 2013) have aimed to determine traditional tests that detect those attempting to feign deficits. They find that on these tests, those who are motivated to perform poorly display "performance not characteristic of patients with brain injuries" (Binder et al., 2003). Other tests are designed specifically to identify malingerers. They do so by superficially appearing highly difficult, but being truly low difficulty, and thus luring malingerers to perform significantly below what is expected, even compared with a population with true deficit (Inman & Berry, 2002). The research on patients intentionally performing poorly is abundant; however, there is less study on those patients who simply lack motivation to perform well.

Collegiate athletes participating in neuropsychological testing may lack motivation to perform well for several reasons. Researchers have noted that post-injury, athletes may be motivated to minimize symptoms, and perform at their best so as to return to play as soon as possible (Bailey et al., 2006; Rabinowitz & Arnett, 2013; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001). Orey et al. (2000) found little difference in performance between a group of students who were given financial incentive to perform well, and a group that was given no incentive to perform well, noting that it may be a result of a generally motivated nature of those college students who participated. However, at baseline, athletes have less incentive to perform at a high level. Further, athletes may be generally disinterested, or not have a full understanding of the importance of baseline testing in determining the effects of an injury. It has been suggested that this poor motivation or lack of motivation may produce unreliable test results (Binder et al., 2003; Bailey et al., 2006; Szabo, Alosco, Fedor, & Gunstad, 2013). If the data derived from baseline testing are unreliable, then the pre-post injury assessment method is uninformative. As such, it is important that test administrators have a way of gauging athlete motivation, so as to measure the usefulness of baseline comparison.

Subjective measures can be useful in describing a general level of athlete motivation; however, more objective measures of motivation may be useful in gaining a deeper understanding of the reliability of intraindividual comparison. Previous research has shown that reaction time (Johnson et al., 2011; Bailey et al., 2006), as well as attention and memory (Echemendia et al., 2001), are often affected post-concussion. There is also some evidence that these measures may be sensitive to motivation (Bailey et al., 2006; Binder et al., 2003; Hubel et al., 2013). The VIGIL (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956) is a test that measures reaction time and attention. Bailey et al. (2006) found that athletes who were identified as having suspect motivation at baseline improved on the VIGIL post-injury compared to those who were identified as having high motivation at baseline, suggesting that this test is sensitive to subjective measures of motivation.

Variability across measures in a single testing event may also be an indicator of motivation. Rabinowitz & Arnett (2013) found that variability across tests in a battery was negatively associated with good overall performance. Further, those individuals who showed greater variability were also more likely to show significant decline post-injury. While some variability is normal, these results may suggest that those individuals who are less motivated to perform well show increased variability across measures. Clinically, it may also suggest that those who show greater variability at baseline are more susceptible to cognitive effects post-concussion. As such, it is of interest to consider how variability in response time across trials of a motivation-sensitive measure such as the VIGIL may be associated with subjective measures of motivation.

Goal of study

The present study aims to identify an objective marker of motivation in collegiate athletes during baseline neuropsychological testing that will help in developing more valid interpretations of the results. By improving the validity of baseline assessments, we can more effectively assess the functional changes caused by concussion.

Hypotheses

Hypothesis 1: Variability in reaction time across trials of the VIGIL will differ between ”Low”, “Moderate”, and “High” motivation groups, with lower motivation groups displaying greater variability.

Hypothesis 2: The “Low” motivation group will have a higher mean standard deviation of reaction time across trials of the VIGIL when compared to “High” motivation group.

Materials and Methods

Participants

Participants for the study were collegiate athletes recruited from The Penn State Sports Concussion Neuropsychology Program. Before participating in collegiate sports, athletes were administered a baseline neuropsychological battery of tests. There were initially 885 participants in the sports concussion program database. Participants were included in analysis if: (1) the subjective experimenter motivation rating for baseline testing was available, (2) baseline VIGIL task data were available and complete, and (3) standard deviation (SD) of reaction time for each VIGIL trial fell within 3 SDs from the mean of that trial (Trial 1: M = 67.43, SD = 24.16; Trial 2: M = 63.86, SD = 22.62; Trial 3: M = 67.26, SD = 24.46; Trial 4: M = 70.97, SD = 26.30). If either (1) or (2) was untrue of computerized participant data, paper files were checked to retrieve all available data.

After removing those participants who did not meet the inclusion criteria, there were a total of 737 male and female student athlete participants at baseline (Age at Baseline: M = 18.51 SD = 1.02). The sports teams represented included: Football, Men's Lacrosse, Women's Soccer, Men's Ice Hockey, Men's Soccer, Women's Lacrosse, Men's Basketball, Women's Basketball, Men's Wrestling, Women's Ice Hockey, Softball, Baseball, and Men's Gymnastics. Characteristics of participants are listed in Table 1.

Table 1. Descriptive measures of "Low", "Moderate", and "High" motivation groups.

Measure	Group 1 "Low" Motivation		Group 2 "Moderate" Motivation		Group 3 "High" Motivation	
	f	%	f	%	f	%
Gender						
Male	53	77.9	347	76.1	151	70.9
Female	15	22.1	109	23.9	62	29.1
Athlete Sport						
Football	27	39.7	146	32.0	63	29.6
Men's Lacrosse	8	11.8	75	16.4	29	13.6
Women's Soccer	6	8.8	38	8.3	35	16.4
Men's Ice Hockey	6	8.8	42	9.2	23	10.8
Men's Soccer	7	10.3	44	9.6	23	10.8
Women's Lacrosse	5	7.4	45	9.9	17	8.0
Men's Basketball	4	5.9	30	6.6	12	5.6
Women's Basketball	3	4.4	23	5.0	7	3.3
Men's Wrestling	0	0	10	2.2	2	0.9
Women's Ice Hockey	1	1.5	0	0	2	0.9
Softball	0	0	2	0.4	0	0
Baseball	1	1.5	0	0	0	0
Men's Gymnastics	0	0	1	0.2	0	0
Ethnicity						
Caucasian	43	63.2	333	73.0	169	79.3
African American	17	25.0	99	21.7	34	16.0
Hispanic American	0	0	6	1.3	3	1.4
Asian American	2	2.9	2	0.4	2	0.9
Biracial/Multiracial	2	2.9	13	2.9	4	1.9
Latin American	2	2.9	0	0	0	0
Other	2	2.9	3	0.7	1	0.5

Note: N = 737 Abbreviations: f = frequency, % = percentage.

Procedure

Participants were administered a baseline neuropsychological assessment battery including both pencil-and-paper and computerized tests of neurocognitive and neurobehavioral functioning. If athletes sustained a concussion during their participation at the collegiate level, they were referred for post-concussion testing by the team doctor or athletic trainer. The test battery was administered by either an undergraduate research assistant or a graduate student under the supervision of a PhD.-level neuropsychologist. The present study only used data from baseline testing.

Measures

A battery of several measures was administered to the athlete to evaluate functioning. These measures assessed characteristics such as memory, reaction time, concentration, processing speed, and affect. The measures used for the present study are listed below:

Motivation Rating.

The testing administrator was asked to subjectively rate the participant based on how hard they believed the athlete was trying during testing. The scale was from 1 to 7, with 1 representing not trying at all and 7 representing as hard as you can imagine trying.

Participants were then divided into three motivational groups based on these ratings: a "Low" motivation group including those who received scores of 1 through 4, a "Moderate" motivation group including those with scores greater than 4 and less than 7, and a "High" motivation group including those who received scores of 7.

VIGIL.

The Vigil is a computerized continuous performance task that measures attention and reaction time. The participant is instructed to press the space bar each time they see the letter "K" appear on the screen. Initially, the test counts down from 5 to 1, then various letters flash on the screen during which time the participant is instructed to respond only when the letter "K" appears. The entire task lasts approximately 4.5-5 minutes. The output data includes the mean and median reaction time for the entire task, as well as the mean, median, and standard deviation broken down by 4 trials. Information is also provided on the number of perseverations, and omission and commission errors. The present study used the SD of reaction time for each trial, as well as a calculated mean SD for the entire task.

Results

The mean standard deviation of reaction time on the VIGIL task was analyzed between three motivation groups: "Low", "Moderate", and "High". Comparison of the mean standard deviation of reaction time over the entire task revealed a trend of higher variability in lower motivation groups. The "Low" motivation group had the highest overall mean (M = 67.28, SD = 15.40) of the three groups, reflecting the highest variability in reaction time. The "High" motivation group had the lowest overall mean (M = 63.40, SD = 14.61) of the three groups, reflecting the lowest overall variability in reaction time. All values are displayed in Table 2. A bivariate analysis further supported a statistically significant (though very small effect size) negative association between raw motivation score and mean variability of the task: $r(735) = -.10$, $p = .005$.

Table 2. Mean standard deviation across VIGIL in three motivation groups.

Motivation Group	n	Mean
"Low"	68	67.28 (15.40)
"Moderate"	456	66.35 (14.77)
"High"	213	63.40 (14.61)

Multivariate analysis of variance revealed a significant effect between the three motivation groups: $\lambda = .978$, $F (3, 374) = 2.088$, $p = .034$.

The “High” motivation group maintained the lowest mean standard deviation (Trial 1: M = 62.92; Trial 2: M = 61.46; Trial 3: M = 63.13; Trial 4: M = 66.07) in each of the four trials. In the first and third trials, the “Moderate” motivation group had the greatest mean standard deviation (Trial 1: M = 66.78; Trial 3: M = 66.59). In the second and fourth trials, the “Low” motivation group had the greatest mean standard deviation (Trial 2: M = 67.40; Trial 4: M = 71.32). Between-group analysis revealed no significant effect of motivation group on any individual VIGIL trial. Results are displayed in Table 3.

Table 3. Output of univariate analysis of each VIGIL trial.

Measure	Group 1 “Low” Mean SD	Group 2 “Moderate” Mean SD	Group 3 “High” Mean SD	Mean Square	F-value (df=2)	p-value
Trial 1	64.97	66.78	62.92	1091.92	2.74	.065
Trial 2	67.40	62.11	61.46	962.01	2.36	.095
Trial 3	65.42	66.59	63.13	869.83	1.97	.140
Trial 4	71.32	69.92	66.07	1288.52	2.62	.073

Discussion

Variability as a measure of motivation

This study aimed to detect an objective measure of motivation that could improve the interpretation of baseline neuropsychological test data among college athletes. Analysis of the data showed an overall effect between the three motivation groups in support of the first hypothesis that variability in reaction time would significantly differ between groups. This is consistent with Rabinowitz & Arnett (2013), who suggested that intraindividual test variability might be affected by an athlete's motivation during the time of testing. However, in the present study, the suggestion that low motivation groups would exhibit higher variability in trials when compared to higher motivation groups was not entirely supported. It was expected that highly motivated athletes would respond more consistently across the task, and show significantly less variability in reaction time when compared to lower motivated athletes. The "Low" group, however, did not consistently perform with greater variability than the "Moderate" group. The multivariate analysis reported no significant differences between the motivation groups on any individual VIGIL trial. The trend of the overall means, however, agreed with the second hypothesis that mean variability would be greater in the less motivated group.

Implications

The overall effect between groups implies that variability might measure some aspect of motivation. The trend of increasing variability with decreasing motivation suggested by the data has important implications for interpretation of the results. If an individual is less motivated to perform well, the results of baseline testing could inaccurately reflect an athlete's true functioning, as suggested by several researchers (Binder et al., 2003; Bailey et al., 2006; Szabo, Alosco, Fedor, & Gunstad, 2013). In these cases, a comparison of a post-concussion test to baseline data would be very difficult to interpret, considering that the data are not truly representative of pre-morbid performance. Identifying objective measures of motivation, and understanding how to improve the validity of tasks that are highly vulnerable to the effects of motivation could allow for neuropsychologists to better interpret changes in functioning.

One issue in considering variability in the context of a single task is that, if variability in overall performance is high, individual tasks would likely not be reliable predictors of the overall performance on a testing battery. Several researchers have reported that some variability in testing is normal. However, if there is high variability, analyzing the results of a single task that lasts only several minutes out of a two-hour long battery may grossly misrepresent an athlete's overall motivation. This is further suggested by the lack of significance between groups on variability on individual trial blocks of the VIGIL that was found in the current study. These short periods of performance output may be too insignificant to truly reflect how the athlete is performing across the entire battery.

While there is the possibility that a single task could be a microcosm of the entire battery, there are several reasons for why this should be questioned. There is extensive crossover in the cognitive domains measured in different tasks, but performance on a single task is not representative of all other tasks. By nature, there will be tasks that are easier and tasks that are more difficult for athletes to perform. Binder, Iverson, & Brooks (2009) reported that having some "abnormal" scores is characteristic of healthy adult performance, and recommended that these deviant outputs be considered in the context of the entire battery, understanding that there is some normal variability. Similarly, motivation measured in one single task might not represent motivation across an entire battery. There are several factors reported to affect an individual's motivation. However, there are two levels of motivation into which these could be divided: (1) acute motivation on a single task which involves an interest in the specific task, the athlete's attention, understanding of the task, and other critical factors; and (2) overall motivation which takes into account the athlete's state during the testing session, and is affected by lethargy, learning disorders, understanding of the purpose of testing, and other more chronic factors. Athlete motivation is likely to fluctuate across the testing period depending on these variables. It might be beneficial to consider how both acute and chronic motivation affect performance. Future research should assess how these different definitions of motivation can affect performance, and if a more critical assessment is beneficial in interpretation of single task results rather than results of the entire battery.

Because the motivation rating is subjective, there are numerous factors that could affect how an examiner rates an athlete's performance. The examiners in the present study included undergraduate research assistants who were trained to administer the tests. However, these examiners likely varied in their level of experience. Those who have less experience with the athletes may have less to compare to—making it more difficult to gauge relative levels of effort from athletes. Further, examiners are focusing much of their attention on administering tests, so they may miss certain cues from the athlete about motivational state. The motivation rating scale requires the selection of a number to represent an abstract concept, which could lead to differential interpretations. Between examiners, definitions of motivation will likely vary. Experimenters may also not be as attentive to an athlete's effort on a computerized task like the VIGIL as they are to effort on tests they are administering themselves.

An important consideration in this analysis was how the motivation groups were divided. It was previously noted that college students are likely to be highly motivated to perform well on a task. The vast majority of athletes were rated on the upper half of the scale, making it somewhat difficult to clearly divide them. The "High" motivation group in this analysis only included participants with the highest rating possible, meaning that the experimenter rated them as trying as hard as they could imagine someone trying. This could, however, reflect an interpretation of an athlete's performance that is not representative of true motivation, but rather of actual success on the tasks administered. IQ has previously been reported to have a positive association with performance on a neuropsychological battery (Leckliter & Matarazzo, 1989). Though it may not be the influence of IQ, per say, an athlete's cognitive ability could likely create an illusion of high motivation to the experimenter. If this were the case, athletes could theoretically receive the highest motivational rating without being truly motivated to perform well at all, but simply having a natural capacity to perform well. It might be favorable to develop a less abstract, more behaviorally-based, rating system of motivation to prevent such misinterpretations.

There are several limitations to this study. The first is that the population was fairly homogenous, coming from similar backgrounds and education levels. Therefore, the results cannot be generalized to populations outside of college level student athletes. Another limitation is that this group was highly motivated, making it difficult to distinguish the effects in a truly unmotivated individual. Lastly, although there is evidence that computerized tests are highly accurate in processing reaction time, there is the possibility of malfunctioning and invalid results. For this reason, participants were removed if their values fell outside of three SD from the mean.

Conclusion

The current study showed some evidence supporting variability as a measure of motivation in baseline neuropsychological testing of college level athletes. However, it should be recognized that different measures of motivation could be assessing different types of motivation, or different factors involved in motivation. As such, it is important to continue to consider how motivation is both displayed and perceived. There are also several variables that affect motivation and cannot be ignored in an analysis of what motivation itself affects.

As several researchers have noted, motivation can confound results and yield unreliable data that affects neuropsychological interpretations. The current widely used practice in concussion assessment is that of baseline and post-injury testing, in which the athlete's baseline results are used to determine how and to what extent their functioning has deviated after a concussion. Because of the often subtle and sub-clinical presentation of the symptoms of these injuries, it is vital that healthcare providers have reliable methods of tracking recovery. There is significant research suggesting that if players return to play too soon, before all of their symptoms are eliminated, they risk the dangerous additive and possibly permanent effects of a second injury. If we are able to more reliably assess changes in functioning without confounds, we can protect these players and help ensure that they are fully recovered before returning them to play.

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