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Pre-existing Anxiety and Vestibular Symptoms: The Relationship to Coordination, Balance, and Reaction Time in College Athletes

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by

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We the undersigned committee hereby approve the attached doctoral research project,
"Pre-existing Anxiety and Vestibular Symptoms: The Relationship to Coordination, Balance, and Reaction Time in College Athletes"

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Abstract

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by Sydney Danielle Hurt, M.A., M.S.

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A growing body of literature suggests that certain pre-existing physical and mental health conditions can contribute to significant differences in important areas of performance among athletes, such as reaction time and balance. These findings have important implications for concussion testing protocols, as factors that potentially skew performance could place the health of athletes at risk by resulting in inaccurate diagnosis or premature return to play following a head injury. Symptoms of both anxiety and vestibular dysfunction, such as dizziness and vertigo, are frequently reported problems in the adult population, and research has documented notable symptom overlap between these two conditions. However, there is little research examining how anxiety and vestibular dysfunction may impact the performance of college athletes on measures of balance and reaction time.

The present study seeks to explore the relationships amongst these variables. Specifically, it was hypothesized that athletes who endorsed symptoms of both anxiety and vestibular dysfunction would have slower reaction time and worse balance than athletes who only endorsed symptoms of one of these conditions, who in turn would have slower reaction time and worse balance than athletes who endorsed no symptoms of either condition. Using an accelerometer-based

measurement of postural stability called Sway, athletes who endorsed no symptoms of anxiety were shown to have better balance than athletes who endorsed at least one symptom of anxiety, $t(237) = 2.73$, $p = .007$, d = .31. Similarly, athletes who endorsed no vestibular symptoms were shown to have better balance than those who endorsed at least one vestibular symptom, $t(359) = 2.14$, $p = .03$, d = .27. Meanwhile, a statistically significant difference in average balance scores was observed between individuals with No Symptoms, symptoms of only One Condition (anxiety or vestibular), and symptoms of Both Conditions (anxiety and vestibular) $F(2, 358) = 5.023$, $p = .007$, $\eta p^2 = .027$. Specifically, the Single Condition group had lower scores and thus worse balance than the No Symptom group (p = .009). Correlational results further demonstrated that as symptoms of anxiety ($r = -.209$, $n = 361$, $p = .000$) or vestibular dysfunction ($r = -.145$, $n = 361$, $p = .006$) increase, balance performance on Sway decreases. On the other hand, no significant differences in reaction time were observed among any of these groups. Overall findings from this study suggest that pre-existing anxiety and vestibular symptoms have a negative impact on balance, supporting the inclusion of measures related to these symptoms in concussion testing protocols with college athletes.

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Chapter 1: Pre-existing Anxiety and Vestibular Symptoms: The Relationship to Coordination, Balance, and Reaction Time in College Athletes

College athletes are at increased risk for sports-related injuries such as concussions, particularly if they participate in contact sports. The National Collegiate Athletic Association (NCAA) Injury Surveillance Program (ISP) found that over a 16-year period from 1988-2004, there were 182,000 injuries and more than 1 million athlete-exposure records, with athlete-exposures defined as 1 athlete participating in 1 practice or game (Hootman et al., 2007). Hootman et al., (2007) also observed that injuries were more likely to happen during games (13.8 injuries for every 1000 athlete-exposures) than practice (4.0 injuries per 1000 athlete-exposures). More recently, during the 2011-2012 through 2014-2015 academic seasons, the NCAA ISP recorded 1,485 concussions sustained across 13 sports and 1,094 team-seasons (a team-season is defined as one team sponsoring one season of sport) with men's wrestling and football, as well as men and women's ice hockey, having the highest average number of concussions sustained per team per season (Kerr et al., 2017). It is of note that the most commonly reported concussion-related symptoms are physical in nature, such as headache, and many of them involve vestibular changes, such as lightheadedness, dizziness, and balance problems (Wasserman et al., 2016). However, many of these symptoms are not exclusive to concussion. This is why it is important to know whether an athlete experienced these symptoms prior to a potential injury, perhaps in relation to other unrelated health conditions. Indeed, awareness of pre-existing physical health is therefore quite beneficial in the context of concussion assessment.

In a similar vein, assessment of athletes' mental health concerns has become an integral component of concussion evaluations, and efforts to maximize student-athletes' well-being in general. In addition to physical symptoms related to injuries, the NCAA has become increasingly invested in the mental health of the athletes as well. Their best practices for mental health currently include encouraging colleges to have student-athletes complete mental health screenings prior to participation in college athletics and referring appropriate athletes for treatment with licensed mental health professionals (NCAA Sport Science Institute, 2016). This is particularly relevant considering the 2016 NCAA Growth, Opportunity, Aspirations and Learning of Students (GOALS) study found an increase in mental health concerns such as anxiety and depression among student-athletes (Paskus & Bell, 2016).

Given these findings, it appears important to investigate how physical symptoms such as dizziness, and mental health symptoms such as anxiety, might impact a student-athlete's baseline performance both on and off the field. For example, if an athlete has pre-existing symptoms of anxiety or dizziness, he or she may perform worse on certain components of a baseline concussion evaluation that measures constructs such as balance and reaction time, even if he or she is not concussed. Additionally, given the significant symptom overlap between anxiety and vestibular dysfunction, it can be quite challenging to differentiate whether commonly related symptoms such as dizziness and slowed reaction time are attributable to a pre-existing condition or an acute injury such as a sports-related concussion. The current study attempts to address some of these challenges by exploring the relationship between anxiety and vestibular symptoms and how they might impact aspects of physical and cognitive performance among non-concussed college athletes.

Anxiety in the United States

While the focus of this study is on college athletes, it is of note that the World Health Organization (WHO) estimates that 3.6% (264 million) of the global population has an anxiety disorder. Globally, anxiety disorders are more prevalent in females (4.6%) than in males (2.6%; WHO, 2015). In the Region of the Americas, which includes both North and South America, 21% (57.22 million) of the population is estimated to have an anxiety disorder. In the United States specifically, 6.3% (18.7 million) of the population is estimated to have an anxiety disorder (WHO, 2015). Additionally, 41.6% of college students in a U.S. survey of college counseling centers reported anxiety as their presenting concern (Association for University and College Counseling Center Directors, 2012). Given the prevalence of anxiety in the general population and in college students specifically, it appears important to develop a better understanding of methods to assess anxiety symptoms and differentiate them from symptoms that may be related to other medical conditions.

Anxiety Disorders

Most anxiety disorders are characterized by both emotional and physical symptoms. For example, according to the Mayo Clinic (2018), common anxiety symptoms include nervousness or feeling on edge, a sense of panic, fear, or doom, elevated heart rate, hyperventilation, sweating, trembling, feeling weak or tired, trouble concentrating, sleep difficulties, difficulty controlling worry, avoiding triggers for anxiety, and gastrointestinal issues. The DSM-5 further defines anxiety disorders as, "disorders that share features of excessive fear and anxiety and related behavioral disturbances," and states that panic attacks are a prominent feature of anxiety disorders (American Psychiatric Association, 2013).

Panic attacks are a primary diagnostic criteria of panic disorder, which is characterized as a discrete period or "attack" of intense fear or discomfort as well as physical symptoms, in addition to fear of experiencing additional attacks and changing behaviors in an attempt to avoid future attacks. Some of the physical symptoms commonly found in panic disorder include heart palpitations or elevated heart rate, sweating, trembling or shaking, shortness of breath, chest pain, nausea, feeling dizzy, lightheaded or faint, numbness or tingling, and chills or hot flashes (APA, 2013). It is of note that symptoms such as nausea, dizziness and feeling lightheaded or faint are not unique to anxiety, as they are also common complaints of people who are experiencing vestibular dysfunction. In addition, individuals with Panic Disorder, particularly those with agoraphobia (anxiety involving being in places or situations from which escape might be difficult or help may not be available in the event of a sudden panic attack), have been found to frequently have co-existing vestibular dysfunction such as dizziness/vertigo as well (Jacob et al., 1996). Some have hypothesized that hyperventilation, which can commonly occur during times of high anxiety and panic attacks, could result in lightheadedness due to a lack of carbon dioxide (CO_2), and as a result contribute to feelings of dizziness and instability (Carmona, Holland, & Harrison, 2009). However, this does not explain why individuals with anxiety and no history of hyperventilation also endorse vestibular symptoms such as vertigo and dizziness. Additionally, previous research provides some support to the hypothesis that anxiety may have a negative impact on the reaction time of athletes on neuropsychological testing (Tomczyk, Shaver, & Hunt, 2020), but the evidence is largely preliminary at this time. The relationship between anxiety disorders and vestibular symptoms thus appears rather complex, and worthy of further exploration.

Vestibular Dysfunction

Vestibular symptoms in general are actually fairly common. From the years 1995-2004, nearly 26 million U.S. people went to the ER for symptoms of dizziness/vertigo (Kerber et al., 2008). A systematic review of studies containing data on the epidemiology of symptoms of balance disorders in adult populations found lifetime prevalence estimates of 17-30% for significant dizziness and of 3-10% lifetime prevalence for vertigo, suggestive that these vestibular symptoms may be more common in the adult population than previously suspected (Murdin & Schilder, 2015).

Vestibular Disorders

In regard to the frequency of specific vestibular disorders, benign paroxysmal positional vertigo (BPPV) is one of the most commonly diagnosed, with other disorders such as vestibular migraines and vestibular neuritis being commonly diagnosed as well (Agrawal, Ward, & Minor, 2013). Certain types of injuries, such as head trauma or concussion, can also cause vestibular symptoms such as transient vertigo and problems with balance (Thompson & Amedee, 2009). However, some individuals never receive a formal diagnosis or thorough explanation for their vestibular symptoms. For example, due to the vague nature of the symptom of "dizziness," and numerous potential etiologies for this symptom, around 20% of cases that present to primary care physicians with "dizziness" do not receive a final diagnosis specifying the underlying cause (Post & Dickerson, 2010). While determining the etiology of symptoms presents a great challenge, in some cases having a better understanding of the history and background regarding vestibular symptoms may provide a more accurate diagnosis.

Anxiety and Vestibular Disorders

Symptom Overlap

As alluded to above, previous research has shown that there is significant symptom overlap between certain psychiatric symptoms, such as anxiety, and common vestibular symptoms, such as dizziness, unsteady balance, and vertigo (Balaban & Jacob, 2001). It remains unclear whether the presence of one type of symptoms triggers the other (i.e., whether vestibular pathology triggers an anxiety disorder or vice versa). However, there is significant evidence that numerous brain structures such as the parabrachial nuclei, hippocampus, cerebellum, and occipital lobe, appear to be involved in both vestibular and psychiatric symptoms (Gurvich et al., 2013), suggesting that similar neuroanatomical regions may be involved in the manifestation of these symptoms regardless of their etiology.

Vestibular symptoms from any source can be a major stressor and have a negative impact on an individual's daily functioning. However, when comparing individuals who all reported dizziness as a major symptom, Eckherdt-Henn et al. (2003) found that those with a psychiatric disorder and those with both vestibular dysfunction and a psychiatric disorder reported significantly more distress from their dizziness compared to those who only had vestibular dysfunction and no psychiatric disorder. Both groups with a psychiatric component to their dizziness also felt more impaired in their jobs and daily activities by their dizziness than the group with vestibular dysfunction with no psychiatric component (Eckhardt-Henn, Breuer, Thomalske, Hoffmann, & Hopf, 2003). This suggests that for people with vestibular symptoms, the co-existing presence of a psychiatric disorder makes these symptoms more disruptive to their lives.

Potential Mechanisms of Unexplained Vestibular Symptoms

As noted above, many individuals presenting with vestibular symptoms never receive a complete explanation or diagnosis for these symptoms. Some have proposed that anxiety could be a major contributor to these unexplained or only partially explained vestibular symptoms. For example, Godemann et al. (2005) evaluated persisting vertigo in individuals with a diagnosis of neuritis vestibularis, and found that individuals reporting persisting vertigo generally did not have pathological results on tests of dynamic posturography, which measures balance control; however, those who reported vertigo were also more likely to report body-related anxiety and anxiety-related apprehension. In terms of underlying mechanisms, it is also of note that similar treatment methods, such as selective serotonin reuptake inhibitors (SSRI’s), benzodiazepines, and tricyclic antidepressants, have been found to be effective for treatment of both balance disorders and anxiety disorders at different dosages (Balaban, Jacob, & Furman, 2011), suggesting there is a similar underlying mechanism causing these symptoms in each condition. The apparent complex dynamics between anxiety and vestibular symptoms thus warrants further research to improve our understanding.

Given the aforementioned prevalence of anxiety disorders in a college population and the frequency of vestibular symptoms after sustaining a concussion, it would be advantageous to explore the relationship between anxiety and vestibular symptoms in a healthy college athlete population specifically. Fortunately, assessing for anxiety and vestibular symptoms is often part of a baseline concussion testing protocol with student-athletes at colleges and universities.

Baseline Concussion Assessments

Psychological Distress

Screening for psychological distress during baseline concussion testing has important clinical implications, as psychological distress may have a negative impact on both reaction time and processing speed, which could result in an inaccurate representation of baseline functioning (Bailey et al., 2010). This could cause further difficulties when comparing post-injury performance to baseline performance, as athletes could be allowed to prematurely return to play due to having a sub-optimal baseline. Bailey et al. (2010) also found that student athletes who endorsed more items on nearly all clinical scales and subscales of a personality inventory had poorer cognitive performance on an online neurocognitive test. Specifically, there appeared to be a significant relationship between psychological distress and poorer performance on concussion baseline testing for student athletes endorsing symptoms of anxiety, depression, substance use, and suicidal ideation. The authors concluded that this psychological distress could lead to suboptimal cognitive performance on baseline testing, which could make it more difficult to identify cognitive dysfunction associated with a concussion post-injury (Bailey et al., 2010). While psychological distress is a common factor contributing to suboptimal performance on a concussion baseline assessment, other medical or physical factors can influence baseline performance as well, particularly during tasks requiring motor coordination or speed.

Disparities in Performance

Motor Coordination

Developmental Factors

Individuals with pre-existing vestibular symptoms may have greater difficulty developing or refining specific physical or motor abilities that may promote athletic achievement and progression. This is because vestibular symptoms such as dizziness and vertigo are known to negatively impact some physical capabilities, such as gait, balance and coordination, and increase the risk of falls and fall-related injuries (Agrawal et al., 2009). Such physical difficulties can be problematic in terms of sports participation and general physical activity. For example, Cairney et al. (2006) found that children with probable developmental coordination disorder were generally less physically active than their peers. Meanwhile, Wrotniak et al. (2006) discovered that children with better motor abilities engaged more in physical activity compared to their peers with poorer motor abilities. They also found that level of motor abilities was inversely related to the amount of time spent in sedentary activity (Wrotniak et al., 2006). While the majority of children who participate in childhood sports do not go on to play at the college level or above, it is important to note that early engagement (or lack thereof) in athletic activities can have a significant impact on motor coordination, and vice versa.

Athletes and Non-Athletes

Meanwhile, there has been extensive research spanning decades suggesting athletes have certain advantages in coordination and related skills compared to non-athletes (e.g., Dorcus, 1923; Schmidt, et al., 2016). An early study examining whether similar training results in the same degree of benefit between athletes and non-athletes found significant differences in hand-eye coordination when comparing varsity athletes of different sports to a non-athlete sample (Korins, 1932). Specifically, Korins found that athletes given time to practice a hand-eye coordination task performed better than athletes who were not given a chance to practice this task, who in turn performed better than a non-athlete sample. Additionally, scores among athletes were uniformly higher in varsity basketball players and fencers compared to varsity swimmers, runners, and high jumpers (Korin, 1932). This suggests that certain types of athletes are more likely to have better motor coordination, potentially making it more difficult to detect a deficit in motor coordination post-injury as their performance might be considered poor for them but still be considered within the normal range for an average individual.

Additionally, the fact that the athletes who were allowed to practice performed best overall compared to both other athletes and non-athletes suggests that motor coordination can improve with repetition. This is relevant as it suggests athletes who have completed a task before (such as in a baseline assessment) may naturally perform better when performing the task again during a post-injury assessment, making it harder to detect if there are any deficits during the second assessment. This phenomenon, commonly called "practice effects," is a common concern in neuropsychological assessment (Calamia, Markon, & Tranel, 2012) and should be considered when assessing student athletes for potential deficits compared to baseline performance.

More contemporary research has established the role of motor coordination and repetition in improving performance in athletic activities. For example, Vandorpe et al. (2012) found that children who consistently participated in club sports over a three-year span displayed better motor coordination than their same aged peers who participated in club sports intermittently or not at all. Similarly, Pion et al. (2015) compared elite and sub-elite female volleyball players over a five-year period to determine whether significant differences existed on a variety of physical capabilities. While they found no differences in anthropometry, flexibility, strength, or speed and agility, they found a significant difference in motor coordination between these two groups. Motor coordination was assessed using subtests examining backward balance, sideways motion, and sideways jumping ability. Pion et al. (2015) asserted that this indicates motor coordination is an important factor when determining which athletes progress to an elite level. Furthermore, a study by Chagas, Ozmun, and Batista (2017) found a positive correlation between motor coordination scores and certain volleyball specific skills among non-athlete adolescents who participated in volleyball during physical education classes. Combined, findings like these suggest that earlier engagement in regular athletic activities can have a positive impact on motor coordination, and those athletes who have spent the most time engaged in athletic activities tend to display higher levels of motor coordination compared to non-athletes as well as fellow athletes with less athletic experience. Many athletes who play their sport at the college level and above have likely participated in athletic activities for several years, suggesting that they are also likely to demonstrate relatively better developed motor skills.

Visual-Spatial Abilities & Mental Rotation

Relative capabilities of athletes participating in sports specifically requiring motor coordination have also been examined. For example, Schmidt et al. (2016) found that individuals currently engaging in certain sports, such as orienteers (sport that involves use of a compass and map to navigate to points on unfamiliar terrain at speed) and gymnasts, had better mental rotation than other athletes such as runners, as well as non-athletes. Arguably, being an orienteer or gymnast involves or requires greater coordination and mental rotation capabilities than being a runner. Indeed, other research has also found significant differences in mental rotation performance among athletes whose sports require greater coordination and mental rotation compared to those who do not (Bressel, et al., 2007).

Some other specific athletic populations have been found to have exceptional cognitive abilities within certain visual-spatial domains. A recent comparison of movement experts, defined as dancers and athletes with at least ten years of experience, to non-experts, who were defined as individuals with less than ten years of experience in formalized sports and dance training, found that that the movement experts outperformed non-experts on spatial working memory tasks involving both full body and hand-only movement sequences, but not verbal memory tasks (Barhorst-Cates, 2018). While the correlational nature of the study does not allow for a direct assertion that involvement in movement activities such as dance and sports leads to greater spatial working memory abilities, it does suggest there is a link between spatial working memory and movement experience.

Vestibular Dysfunction

Impact on Visual-Spatial Abilities & Mental Rotation

Meanwhile, certain visual-spatial and mental rotation abilities have also been studied in the context of vestibular dysfunction. For example, individuals with BPPV or vestibular neuritis have been shown to have impaired mental rotation abilities compared to individuals without vestibular dysfunction (Candidi et al., 2013). Similar deficits in mental rotation have been discovered in individuals with Meniere's disease as well (Peruch et al., 2011), which is an inner ear disorder that includes recurrent spells of vertigo, tinnitus or ringing in ears, and hearing loss (Mayo Clinic; 2018). This suggests that individuals with vestibular conditions have difficulty with certain cognitive tasks, particularly in terms of visual-spatial abilities. Vestibular dysfunction has also been preliminarily linked to deficits in related cognitive tasks such as navigational and spatial memory as well (Gurvich et al, 2016). Combined, these results suggest that it is important to keep in mind the respective roles that both level of athletic experience and vestibular dysfunction could play in certain visual-spatial cognitive abilities. Specifically, level of athletic experience appears to be related to better motor coordination and visual-spatial abilities, while vestibular dysfunction appears to be related to poorer abilities in these areas. Awareness of these variables may also assist in determining whether fluctuations in a particular student athlete's performance on visual-spatial tasks can be attributed to pre-existing factors or acute conditions such as a sports-related concussion.

While the overlap in anxiety and vestibular symptoms has been established, the prevalence of and relationship between these symptoms within an athletic population specifically has not been extensively studied. Given the additional importance of being able to accurately assess athletes who have sustained a possible concussion, it is essential to be aware of pre-existing anxiety and vestibular symptoms in a college athlete population and how these symptoms could affect their performance on certain components of concussion testing, particularly with respect to balance and aspects of cognition. Therefore, this study specifically aims to explore the degree to which pre-existing anxiety and vestibular symptoms might be related to aspects of baseline concussion assessments, such as balance and visual reaction time. Given existing research outlined above, it is hypothesized that athletes who endorse these pre-existing symptoms will perform worse on these outcome measures.

Chapter 2: Objectives and Hypotheses

Objective 1: Determine whether there is a significant difference in balance and visually-mediated reaction time between those athletes who endorse only pre-existing anxiety and athletes that do not endorse either pre-existing anxiety or vestibular symptoms. Bailey et al. (2010) found a significant relationship between psychological distress and poorer performance on concussion baseline testing in terms of reaction time and processing speed among student-athletes endorsing symptoms of anxiety, depression, substance use, and suicidal ideation. This study seeks to determine if athletes who endorse symptoms of anxiety display similar results in their performance on baseline concussion testing.

***Hypothesis 1**:* Individuals who endorse pre-existing anxiety only will have poorer balance and reaction time than those who do not endorse pre-existing anxiety or vestibular symptoms.

Objective 2: Determine whether there is a significant difference in balance and visually-mediated reaction time between those athletes who endorse only pre-existing vestibular symptoms and athletes that do not endorse any symptoms. Significant differences have been found in mental rotation performance among athletes whose sports require greater coordination and mental rotation compared to those who do not (Bressel, et al., 2007), with the athletes whose sports require these skills generally outperforming their peers whose sports place less emphasis on these abilities. However, vestibular dysfunction and certain vestibular dysfunction has been found to negatively impact performance on mental rotation abilities (Candidi et al., 2013; Peruch et al., 2011) which in turn typically means poorer coordination as well. This indicates that typically athletes would be expected to perform well on tasks involving mental rotation and coordination, while the presence of vestibular symptoms would negatively impact performance on these tasks.

Hypothesis 2: Individuals who endorse pre-existing vestibular symptoms only will have poorer balance and reaction time than those who do not endorse either pre-existing anxiety or vestibular symptoms.

Objective 3: Determine whether there is a significant difference in balance and visually-mediated reaction time between athletes who do not endorse pre-existing anxiety or vestibular problems and athletes who endorse either anxiety or vestibular problems and those athletes that do not endorse any symptoms of either condition. Anxiety has been found to be associated with a variety of physical symptoms including trembling or shaking, shortness of breath, dizziness, and feeling lightheaded or faint (APA, 2013), which can negatively impact coordination and reaction time. On a similar note, individuals with vestibular problems typically have difficulties with certain physical capabilities, such as gait, balance and coordination (Agrawal et al., 2009). Additionally, Eckhardt-Henn et al. (2003)

found that for people with co-occurring vestibular symptoms and psychiatric disorders find their vestibular symptoms more disruptive to their lives and feel more impaired than individuals who only have vestibular symptoms. When taken in conjunction with the previously cited research on the negative impact of anxiety and vestibular symptoms on baseline concussion testing, there is significant evidence to suggest that the presence of both conditions would have a strong negative impact on aspects of performance compared to athletes who endorse either anxiety or vestibular dysfunction and those who do not endorse either. A goal of this study is to examine balance and visually-mediated reaction time performance of athletes who endorse both anxiety and vestibular dysfunction, and determine the extent to which their performance on these tasks might be different from their peers who endorse symptoms of only one of these conditions, as well as their asymptomatic peers.

Hypothesis 3: Individuals who endorse pre-existing anxiety and vestibular symptoms will have poorer balance and reaction time than those who do endorse either pre-existing anxiety or vestibular symptoms, and those who do not endorse either anxiety or vestibular symptoms.

Chapter 3: Method and Procedures

Data Collection

This study utilized an archival dataset collected during the 2019-2020 academic seasons by the Florida Institute of Technology (FIT) Concussion Management Program. FIT is a private university located in East Central Florida. The participant sample included NCAA division II athletes. All participants completed a pre-participation baseline evaluation through the Concussion Management Program with a standard assessment battery including a baseline questionnaire with vestibular questions and measures of effort, cognition, mood, and balance, including the Patient Health Questionnaire (PHQ-9), Sport Concussion Assessment Tool (SCAT-5) Baseline version, Balance Error Scoring System (BESS), General Anxiety Disorder Seven Item Scale (GAD-7), and Sway Balance App.

Measures

PHQ-9

The PHQ-9 is a 9-item self-report screening measure designed to measure depression severity. It measures the frequency of symptoms, the presence and frequency of suicidal ideation, and the degree to which the endorsed symptoms have impacted the individual’s functioning (Kroenke, Spitzer, & Williams, 2001).

SCAT-5

The SCAT-5 is a tool used for the acute evaluation of suspected sports-related concussion (Echemendia et al., 2017). Individuals complete a baseline assessment including a symptom checklist, immediate and delayed recall of a word list, digits backward, rapid neurological screen, and BESS/mBESS, which is then compared to their performance after a suspected concussion. The symptom checklist includes a variety of symptoms including physical symptoms such as headache, dizziness, and fatigue as well as cognitive symptoms including difficulty concentrating, confusion, and irritability. For the purposes of this study, athletes' endorsements of baseline symptoms of dizziness, pressure in the head, nausea/vomiting, and balance problems were examined as evidence of pre-existing vestibular dysfunction. Evaluation of the SCAT5 found that it is most useful immediately post-injury when determining concussed from non-concussed athletes when using either normative or individual baseline/post-injury comparisons. The diagnostic utility of the SCAT does appear to decrease significantly 3-5 days post-injury (Echemendia et al., 2017).

BESS

Measurements of balance are commonly included in baseline concussion testing of athletes to determine whether pre-existing balance problems exist such that symptoms solely attributable to concussion after an injury can be more accurately determined before returning an athlete to play. The Balance Error Scoring System (BESS) is a measure used to evaluate balance (Bell, Guskiewicz, Clark, & Padua, 2011). The examiner has the examinee hold three different stances with their eyes closed and hands on hips for twenty seconds, and counts how many balance errors the examinee makes during the twenty-second time period. Errors are defined as opening eyes, removing hands from hips, falling, stumbling, or stepping out of the stance, lifting forefoot or heel, abducting the hip more than 30 degrees, and failure to return to the stance in 5 seconds. The BESS has moderate to good reliability to assess static balance and correlates with other measures of balance using testing devices. Additionally, the BESS is valid to detect balance deficits when there are large deficits, such as fatigue or concussion (Bell et al., 2011). The BESS was administered as an embedded component of the Sports Concussion Tool (SCAT-5).

Sway Balance System

The Sway Balance System is an app that assesses balance via postural sway, and simple visually-mediated reaction time (Brett, Zuckerman, Terry, Solomon, & Iverson, 2018) using the triaxial accelerometer built into iOS mobile devices such as iPhones. The balance component of Sway includes five stances (e.g., feet together, tandem stance with left foot and right foot forward, and single leg right and left foot). The participant holds each stance for ten seconds and performs two or three consecutive baseline trials depending on consistency. Stances are scored on a scale from 0-100, where higher scores equaling greater stability, and thus better balance. The scores for each of these five stances are combined to provide an average score for each participant. Participants also complete a visual-motor task of reaction time where they must move or shake their mobile device as quickly as possible as soon as they notice that the screen changes color from white to orange. This task therefore involves a visually-mediated component (e.g., looking at the screen and detecting a change in color), as well as a gross motor coordination component (e.g., promptly moving the device that is being held in their hands). An average reaction time score is then calculated based on performance on this task over five consecutive trials. Participants complete three consecutive trials of these balance and reaction time tasks for the purposes of establishing a baseline. Scores from each of these trials were then averaged together to provide overall composite scores for both balance and reaction time, with higher scores yielding better performance. Sway's baseline balance and reaction time composite scores can also be used for post-injury comparisons, in conjunction with age and sex-based norms, to assist in the assessment and management of concussions (Brett et al., 2018).

GAD-7

The Generalized Anxiety Disorder 7-item scale (GAD-7) is a brief self-report scale designed to assess probable Generalized Anxiety Disorder (Spitzer, Kroenke, Williams, & Lowe, 2006). The GAD-7 asks individuals to rate items on a 0-3 Likert scale, where 0 is not at all and 3 is nearly every day. Examples of items include feeling nervous, anxious, or on edge, worrying too much about different things, and feeling so restless that it is hard to sit still. The GAD-7 divides anxiety into the following levels: scores of 1-5 are considered in the mild range, 6-10 are in the moderate range, 11-15 are in the moderately severe range, and scores of 16-21 are considered in the severe range. Increasing scores on the GAD-7 are strongly associated with multiple domains of functional impairment such as physical functioning, bodily pain, vitality, and mental health (Spitzer et al., 2006).

Vestibular Symptoms

There are specific vestibular measures such as the Vestibular Symptom Scale (VSS) and Vestibular Symptom Scale – Short Form (VSS-SF), which asks in-depth questions about vestibular symptoms and symptom duration to provide multiple subscale scores as well as a total score. However, for the purposes of this study, a shorter, less comprehensive series of questions regarding vestibular symptoms was used so as not to significantly extend the completion time of the battery. As previously mentioned, this information was administered as a built-in element of the SCAT5 and included symptoms of vertigo/dizzy spells, nausea, feelings of pressure in the head, and difficulty with balance.

Analysis of Data

Prior to analyzing data, approval from the Florida Institute of Technology Institutional Review Board (IRB) was obtained by the researcher. Descriptive statistics including assessment of means, standard deviations, and frequencies, and were calculated for participant demographic variables for the primary outcomes. Independent-samples *t*-tests were conducted to determine the relationship between two conditions. Statistical analysis was completed using Statistical Package for the Social Sciences (SPSS) - Version 27.

Participants

The original total sample was initially comprised of 452 individuals who were college athletes at the Florida Institute of Technology during the 2019-2020 athletic season. Numerous participants had to be excluded due to missing data points, resulting in a final sample of 361 athletes. Participants ranged in age from 17-26 (M = 19.77, SD = 1.6) and consisted of 64% (n = 231) males and 36% (n = 120) females. Participants were 70.9% (n = 256) White, 13% (n = 47) African American, 8.6% (n =33) Two or More Races, 6.1% (n = 22) Hispanic/Latino, 1.1% (n = 4) Asian, and 0.3% (n = 1) American Indian/Alaskan Native. Participants were from 17 different sport teams including 12.7% (n = 46) football, 12.2% (n = 44) men's lacrosse, 8% (n = 29) men's swimming, 7.8% (n = 28) men's rowing and 7.8% (n = 28) dance/cheer, 6.1% (n = 22) men's soccer and 6.1% (n = 22) women's swimming, 5.8% (*n* = 21) women's rowing, 5.3% (*n* = 19) softball, 4.4% (*n* = 16) baseball and 4.4% (*n* = 16) women's lacrosse, 4.2% (*n* = 15) men's basketball, 3.9% (*n* = 14) women's volleyball, 3.6% (*n* = 13) men's golf, 3% (*n* = 11) women's basketball, 2.8% (*n* = 10) men's cross country, and 1.9% (*n* = 7) women's cross country.

Anxiety. On the GAD-7, 61.5% (*n* = 222) of participants did not endorse any symptoms of anxiety compared to 38.5% (*n* = 139) of participants who endorsed at least one symptom. Based on GAD-7 scores for specifying severity of anxiety described above, 88.5% (*n* = 123) were classified as mild, 7.2% (*n* = 10) were classified as moderate, and 4.3% (*n* = 6) were classified as moderately severe. None of the participants endorsed severe anxiety.

Vestibular Symptoms. On the SCAT5, participants were asked to indicate whether they typically experienced symptoms of vertigo/dizzy spells, nausea, feelings of pressure in the head, and/or difficulty with balance. Their responses indicated that 76.5% (*n* = 276) did not endorse any of those symptoms compared to 23.5% (*n* = 85) who endorsed at least one of the symptoms. Of those 85 who endorsed symptoms, the majority (68.2%; *n* = 58) only endorsed one of the four symptoms, while 25.9% (*n* = 22) endorsed two symptoms, 4.7% (*n* = 4) endorsed three symptoms, and 1.2% (*n* = 1) endorsed all four symptoms.

Statistical Analyses

Anxiety. To determine the relationship between anxiety and balance, total score on the GAD-7 was correlated with the Sway composite balance score, which yielded a significant negative correlation (r = -.209, n = 361, p = .000). This suggests that as anxiety level increases, balance performance on Sway decreases. Independent samples t-tests were then conducted to examine whether athletes who endorsed any symptoms on the GAD-7 (Anxiety Group) had different balance scores or reaction times on Sway compared to athletes who endorsed no symptoms on the GAD-7 (No Anxiety Group). Levene's test indicated unequal variances (F = 9.39, p = .002), so degrees of freedom were adjusted from 359 to 237. Composite balance scores on Sway were subsequently found to be higher for the No Anxiety Group (M = 82.29, SD = 10.38) than the Anxiety Group (M = 78.60, SD = 13.62), t(237) = 2.73, p = .007, d = .31, suggesting that athletes without any symptoms of anxiety have better balance than athletes with at least one symptom of anxiety, which partially supports our first hypothesis. However, there was no difference between reaction time scores when comparing the No Anxiety Group (M = 77.67, SD = 8.45) to the Anxiety Group (M = 76.83, SD = 8.58), t(359) = .912, p = .362, d = .10. Meanwhile, a positive correlation was found between total scores on the GAD-7 and total errors on the BESS (r = .112, n = 361, p = .03), similarly suggesting that as anxiety increases, an athlete's balance decreases as measured by number of errors on the BESS. However, results of an independent samples t-test found no significant difference in total errors on the BESS between athletes in the Anxiety Group (*M* = 3.88, *SD* = 4.12) and athletes in the No Anxiety Group (*M* = 3.23, *SD* = 3.27), *t*(359) = -1.66, *p* =.10, d = -.18.

Vestibular. To determine the relationship between endorsement of vestibular symptoms and balance, the total number of SCAT5 vestibular questions endorsed was correlated with Sway composite balance scores, which yielded a significant negative correlation (*r* = -.145, *n* = 361, *p* = .006). This suggests that as vestibular symptoms increase, balance decreases based on Sway balance composite scores. Independent samples t-tests were then conducted to examine whether athletes who endorsed any vestibular symptoms (vertigo/dizzy spells, nausea, feelings of pressure in the head, and/or difficulty with balance) on the SCAT5 (Vestibular Group) had lower Sway balance scores or slower reaction time scores than athletes who did not endorse any of these vestibular symptoms (No Vestibular Group). There was a statistically significant difference in Sway composite balance scores between the Vestibular Group (*M* = 78.47, *SD* = 13.18) and the No Vestibular group (*M* = 81.60, *SD* = 11.34), *t*(359) = 2.14, *p* = .03, d = .27, suggesting poorer balance among individuals who endorsed vestibular symptoms. This partially supports our second hypothesis; however, no difference was observed in Sway reaction time scores between the SCAT5 Vestibular group (*M* = 76.85, *SD* = 9.08) and the SCAT5 No Vestibular group (*M* = 77.50, *SD* = 8.32), *t*(359) = .624, *p* = .53, d = .08.

A correlation was also computed to assess the relationship between SCAT5 vestibular symptoms and total errors on the BESS, but results did not indicate any significant association between these two variables (*r* = -.028, *n* = 361, *p* = .60). An independent samples t-test was also conducted to examine whether athletes who endorsed any vestibular symptoms (vertigo/dizzy spells, nausea, feelings of pressure in the head, and/or difficulty with balance) on the SCAT5 had a different number of total errors on the BESS than athletes who did not endorse any of the vestibular symptoms. However, results demonstrated no significant difference in total errors on the BESS for the Vestibular Group (*M* = 3.38, *SD* = 3.46) compared to the No Vestibular Group (*M* = 3.52, *SD* = 3.69), *t*(359) = .31, *p* = .75, d = .04.

Anxiety & Vestibular Symptoms. For the purposes of evaluating the impact of experiencing both anxiety and vestibular symptoms on balance and reaction time, participants were divided into three groups based on their endorsement of vestibular symptoms on the SCAT5 and/or anxiety symptoms on the GAD-7: 196 athletes (54.3%) endorsed no anxiety or vestibular symptoms (No Symptom Group), 128 athletes (35.5%) endorsed either anxiety or vestibular symptoms (Single Condition Group), and 37 athletes (10.2%) endorsed both anxiety and vestibular symptoms (Combined Group).

A statistically significant difference in average Sway composite balance scores was observed among these three groups as determined by one-way ANOVA $F(2, 358) = 5.023$, $p = .007$, $\eta p^2 = .027$. A post-hoc Tukey test revealed that the No Symptom Group differed significantly from the Single Condition Group ($p = .009$), in that the Single Condition group had lower scores and thus worse balance. However, the Combined group was not significantly different from the other two groups.

Meanwhile, there were no statistically significant differences in total errors on the BESS between group means as determined by one-way ANOVA ($F(2, 358) = 1.227$, $p = .294$, $\eta p^2 = .007$). Similarly, a one-way ANOVA also did not find a statistically significant difference in average Sway reaction time scores between groups $F(2, 358) = .914$, $p = .402$, $\eta p^2 = .005$. Hypothesis #3 was therefore only partially supported.

Chapter 4: Discussion

Impact of Study

As previously discussed, exploring whether certain pre-existing factors such as anxiety or vestibular symptoms have a significant impact on an athlete's performance during baseline concussion testing protocols might influence interpretations of post-concussion testing results. Specifically, identifying whether these athletes have a higher propensity towards balance errors or a slower reaction time compared to athletes without a history of these symptoms can inform their diagnosis and treatment, and ultimately may reduce the risk of premature return to play.

Correlations were observed between GAD-7 total scores and both Sway balance composite scores and total errors on the BESS, suggesting that as anxiety increases, balance decreases. Additionally, individuals endorsing any symptoms of anxiety demonstrated worse balance on Sway compared to individuals endorsing no anxiety symptoms. This partially supports the first hypotheses. However, no significant differences were found on the BESS when comparing athletes who endorsed anxiety symptoms to athletes who did not. Similarly, a correlation was observed between vestibular symptoms and Sway balance composite scores, suggesting that endorsement of vestibular symptoms is related to poorer balance, and individuals endorsing any vestibular symptoms demonstrated worse balance on

Sway compared to individuals endorsing no vestibular symptoms. This partially supports the second hypotheses. However, once again, no significant differences found on the BESS when comparing athletes who endorsed vestibular symptoms to athletes who did not. Additionally, no differences in reaction time, as measured by Sway, were observed among any of these groups.

Results from the present study partially supported the third hypothesis as well, as athletes who endorsed either anxiety or vestibular symptoms had worse balance than athletes who did not endorse symptoms of either. This is consistent with previous research stating factors such as gait, balance, and coordination are known to be negatively impacted by vestibular symptoms such as dizziness and vertigo (Agrawal et al., 2009). However, there was no significant difference in reaction time between these two groups. These results are inconsistent with previous research by Bailey et al., (2010), who found that psychological distress may have a negative impact on reaction time in athletes completing a baseline concussion testing protocol.

The lack of significance in reaction time differences observed in the current study could be due to the simplicity of the measure of reaction time used. Specifically, the Sway reaction time task simply requires participants to move their mobile device being held in their hands as quickly as possible when they see that the color changes on the screen. This is a much less sophisticated task compared to other standard neuropsychological measures of reaction time, which often measure reaction time in more than one context, and using a computer mouse or keypad. Therefore, the Sway reaction time task may not be as sensitive to changes in reaction time performance. Additionally, occasional difficulties were observed during administration of this task in terms of getting the mobile device to register smaller, less intense movements, raising the possibility that scores could underestimate actual reaction time and thus decrease the likelihood of detecting a significant difference between groups. Given that other researchers have observed differences in reaction time (Baily et. al, 2010) and visual-spatial abilities (e.g., Candidi et al., 2013; Peruch et al., 2011) among individuals with anxiety and vestibular problems, respectively, future research might be advised to include a wider variety of measures to assess reaction time and visual-spatial functioning.

While it was hypothesized that similar results would be found using both the BESS and Sway as measures of balance, this was also not borne out by the data. The exact reason for this is unknown; however, it appears possible that Sway may be more sensitive to balance changes among individuals with anxiety and/or vestibular problems compared to the BESS. Specifically, given the highly technologically advanced method by which Sway assesses balance performance using the accelerometer in a smartphone device, it is possible that subtle fluctuations in balance performance may have been more easily detected in comparison to the method used in the BESS of having a human examiner evaluate errors using criteria such as opening eyes, removing hands from hips, and falling, stumbling, or stepping out of the stance. Use of this technology perhaps allows Sway to measure more minute differences in balance and postural sway compared to BESS, which measures errors that are well-defined but also more obvious so as to be easily detected by the human eye. Therefore, it is conceivable that individuals may have fluctuations in balance that are recognized by Sway and thus lower the overall score, but similar fluctuations may not fall into the category of an error on the BESS.

No significant difference was found between athletes who endorsed either anxiety or vestibular symptoms and those who endorsed current symptoms of both conditions. This does not support this study's third hypothesis, which predicted that there would be a significant difference between these two groups. While Eckhardt-Henn et al. (2003) found that people with co-occurring vestibular symptoms and psychiatric disorders feel that their functioning is more negatively impacted by their vestibular symptoms than individuals who only have vestibular symptoms, results from the current study were unable to support their findings. There was also no evidence found to support the hypothesis that individuals who endorsed both anxiety and vestibular symptoms would have more balance problems and a slower reaction time than athletes who endorsed either anxiety or vestibular symptoms. It is possible that a lack of significant differences between groups could be due to the relatively small sample size, as only 37 athletes endorsed both anxiety and vestibular symptoms compared to 128 athletes who endorsed at least one symptom of either anxiety or vestibular dysfunction. This large discrepancy in sample sizes makes it more difficult to determine if there is a true difference between the two groups.

Limitations and Areas for Future Research

Indeed, perhaps the most notable limitation of the dataset used in this study is that there was an extremely small number of participants who endorsed both anxiety and vestibular symptoms compared to athletes who endorsed one condition or no symptoms at all. Additionally, the restricted range of variability among individuals endorsing items on the GAD-7 and vestibular items on the SCAT5 is another significant limitation of this study. The majority of athletes sampled had low levels of endorsements for anxiety and/or vestibular symptoms, resulting in an uneven distribution in terms of higher levels of endorsement. For example, no participants endorsed severe levels of anxiety on the GAD-7, so this level was unable to be included in data analysis. As a result of these low levels of symptom endorsements, a cutoff score of 1 symptom endorsed was chosen when distributing athletes into anxiety and vestibular groups, which is less than ideal. Endorsing a single symptom of current anxiety or vestibular dysfunction is not indicative of a history of clinically significant anxiety or vestibular problems. The small number of participants endorsing anxiety and vestibular symptoms also makes it difficult to claim that this study's results are generalizable to the college athlete population at large. Future researchers are encouraged to collect a larger sample of college athletes who endorse both anxiety and vestibular symptoms to determine if this study's findings are replicable. In fact, future studies should not only try to include larger sample sizes, but also attempt to include individuals endorsing higher levels of anxiety and/or vestibular symptoms to assist with determining the degree to which clinically significant degrees of these conditions might interfere with balance and/or reaction time.

Finally, determination of whether participants had a history of vestibular problems was based on their responses to the vestibular questions of the SCAT5. While this includes common vestibular symptoms such as dizziness/vertigo and difficulties with balance, it is unknown whether these individuals ever had a formal diagnosis of vestibular dysfunction. Future studies may find it beneficial to instead use a standardized and validated instrument for assessing vestibular dysfunction, such as the previously mentioned Vestibular Symptom Scale-Short Form. This may provide more accurate information regarding the nature of the participants' vestibular symptoms as well as allow for stronger conclusions to be drawn regarding their impact on reaction time and balance.

Conclusion

Although the data did not completely support the proposed hypotheses, the results of this study still suggested that individuals reporting anxiety and vestibular symptoms appear to have greater balance problems to some degree as measured by Sway. This provides important clinical information to professionals working with athletes at risk for concussion, given that balance problems are fairly common following a concussion, but may need to be interpreted with greater caution among individuals with a history of anxiety and/or vestibular problems. Indeed, it is important for those who are tasked with managing the health of these athletes to be knowledgeable about potential factors that could impact performance on certain concussion assessment measures and make it more difficult to accurately diagnose a potential concussion. Having additional information regarding the nature of these risk factors and how they might impact an athlete's performance could enable professionals to extend additional care to athletes when it comes to determining their readiness to return to play following a suspected concussion toward reducing their risk. For both the protection of the athletes and the benefit of those are tasked with assessing them, examining methods to potentially adapt and improve current concussion assessment and management protocols is an important part of working with this population.

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