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Headache Disorders and Neurocognitive Performance Pre- and Post-Concussive Injury

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We the undersigned committee, having examined the submitted doctoral research project, "Headache Disorders and Neurocognitive Performance Pre- and Post-Concussive Injury" by Kaci Gorres, M.S., hereby indicate its unanimous approval.

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Abstract

Title: Headache Disorders and Neurocognitive Performance Pre- and Post-Concussive Injury

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Objective: The aim of this study is to examine the relationship between pre-existing headache disorders, such as headache or migraine, and neurocognitive testing obtained before and after college-athletes sustain a concussion.

Method: A total of 1129 NCAA Division II college athletes from Florida Tech were included in the present study. Participants were included in this study if they completed baseline and/or post-trauma neuropsychological evaluations that included the Sports Concussion Assessment Tool – Fifth Edition (SCAT-5) and Immediate Post-Concussion Assessment and Cognitive Tool (ImPACT). Athletes' headache and/or migraine history was self-reported at baseline and indicated their position in headache history or non-headache history groups. Additionally, athletes self-reported their most recent prior concussion recovery time in a self-report manner.

Results: Results showed that athletes with a history of headache and/or migraine reported more symptoms and increased symptom severity at baseline compared to athletes with no history of headache and/or migraine. In addition, athletes with a headache history performed significantly worse on ImPACT visual memory and demonstrated significantly lower performance on psychomotor speed composites. Although larger differences from baseline to post-trauma were not observed in athletes with a headache history when accounting for baseline symptoms, headache history athletes did report significantly longer recovery times for prior suspected concussions.

Conclusion: This study provides more evidence toward the influence pre-existing headaches and/or migraines in a collegiate athlete population prior to and following a concussion. Furthermore, this study indicates a need for future research narrowing the scope on specific headache and migraine factors, such as migraine with and without aura, on neurocognitive testing with the SCAT-5 and ImPACT test. In addition, aspects of this study indicate the importance of utilizing individualized baseline comparisons rather than group norming based on significant differences in performances across athletes with and without a headache history. However, if future research continues to find differences amongst these groups, it is hoped a normed baseline group specific to headache and/or migraine history will be considered. Lastly, it is imperative that separate recommendations are made and tailored to individual athletes with a history of headache and/or migraine based on differences amongst symptoms, severity of symptoms, and neurocognitive testing (e.g., visual memory, reaction time, visual motor speed), albeit future research should examine which kind of recommendations should be made.

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List of Terms

Baseline Evaluation – A neurocognitive evaluation occurring prior to participation in athletics in order to assess premorbid ability.

Follow-Up evaluation – A neurocognitive evaluation used to assess for readiness to return to play.

Headache – A painful sensation in the head that ranges in severity and may co-occur with other symptoms.

Immediate Post-concussion Assessment and Cognitive Testing (ImPACT) – The most frequently used computerized neurocognitive test for concussion management. Can be administered in an individual or group setting.

Nociceptive – The perception or the sensation of pain.

Migraine – A neurological disease that falls within the primary headache disorder classification and is often evidenced by several symptoms including moderate to severe head pain, sensitivity to light, sound, and/or smells, and nausea.

Mild Traumatic Brain Injury (mTBI) – Physiological disruption of brain function as a result of trauma that does not exceed loss of consciousness for 30+ minutes, posttraumatic amnesia not greater than 24 hours, nor an initial Glasgow Coma Scale of 13-25 after 30 minutes (APA, 2016).

Post-Trauma/Post-Injury Evaluation – Neurocognitive evaluation that occurs during the acute phase of a concussion injury.

Post-traumatic headache (PTH) – A headache that develops within seven days of an injury or after consciousness is regained.

Primary headache – A classification of headache that is caused by independent factors and not by other disorders. Examples of primary headache disorders include migraine, tension-type headache, and cluster headache.

Secondary headache – A classification of headache that is caused by underlying disorders. Examples of secondary headaches include headache due to trauma or injury to the head or neck and headache attributed to cranial or cervical vascular disorder.

Sport-related concussion (SRC) – the most common form of mild traumatic brain injury. Occurs from biomechanical forces within the context of sport.

Sports Concussion Assessment Tool (SCAT) – A concussion screening tool that incorporates cognitive, symptom, and balance assessment.

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Chapter 1: Introduction

The aim of this study is to examine the relationship between pre-existing headache disorders, such as headache or migraine, and neurocognitive testing obtained before and after college-athletes sustain a concussion. Comparisons among individuals with a history of headache or migraine and those without were generated based on their respective baseline, initial post-traumatic, and follow-up evaluations for sport-related concussions. While headaches are one of the most common symptoms following a concussion, many people experience headaches without a history of head injury. This headache history may place individuals at greater risk for a more complicated recovery if they sustain a concussion. Concussion evaluation and management protocols exist to accurately identify concussions when they occur and facilitate recovery. Concussion assessments typically include a variety of tools to measure cognitive, physical, and emotional symptoms. For this study, baseline, post-trauma, and follow-up performance on these measures were analyzed from the sample of athletes, with domains including immediate and delayed memory, reaction time, concentration, working memory, balance, emotionality, physical symptoms (e.g., headache, nausea, light sensitivity), and sleep. Results of this study provide additional data on the impact pre-existing headache disorders may have on performance across neurocognitive measures for concussion, with an emphasis on any significant changes which may be noted in baseline performance, post-traumatic symptom severity, and recovery time.

Chapter 2: Literature Review

A concussion is a type of mild traumatic brain injury (mTBI) that is often caused by a jolt or bump to the head and results in the brain moving around in the skull (Center for Disease Control and Prevention, 2019). Concussions can result from a variety of different mechanisms, including a direct blow to the head, such as falling or being struck by an object, head-to-head collisions, and even “whiplash”-type injuries, where the head is jolted violently causing an acceleration of the brain against the skull (Hubertus et al., 2019). The leading causes of concussion include falls, automobile collisions, being unintentionally struck by an object or against an obstacle, assaults, and sports (Center for Disease Control and Prevention, 2010). In some instances, a concussion can lead to chemical changes in the brain, and potentially even damaged brain cells (Center for Disease Control and Prevention, 2019). Although damaged brain cells are a possibility, no abnormality can be seen on traditional structural neuroimaging studies (i.e., CT and MRI) with many of the clinical signs and symptoms instead reflecting more functional disturbance and some short-lived impairment of neurological functioning that resolves spontaneously, with some cases evolving over a number of minutes or hours (McCrory et al., 2017).

Neurobiology of Concussions

The change in neurological functioning following a concussive brain injury is a result of a pathophysiological change in the brain (Giza & Hovda, 2014.) The first change immediately following an injury includes an efflux in potassium and influx in sodium and calcium ions as well as the release of glutamate, which leads to depolarization (Katayama et al., 1990). As a result of ionic changes and depolarization, a “spreading depression-like” state is created, which likely contributes to acute concussion symptoms (Giza &

Hovda, 2014). As membrane ionic pumps are acting rapidly, high amounts of energy are being used in the form of adenosine triphosphate (ATP); however, at the same time, there is a reduction in blood flow to the brain, which leads to an energy imbalance and concussive symptomology (Choe, 2016).

In addition to these ionic changes, a concussive injury can cause microstructural injuries in the brain, which are referred to as physical changes that do not appear on traditional brain imaging (i.e., CT scan) but have been recently detectable through more advanced neuroimaging, such as diffusion tensor imaging (DTI; Gardner et al., 2012). These microstructural injuries are more often seen in the neuron and glial cells and result in an imbalance of calcium within the cell (Weber, 2012). When calcium levels are elevated, the mitochondria of the cell are at risk of damage which may ultimately lead to apoptosis (cell death) and improper neurotransmission (Buki & Povlishock, 2006). Specifically, the receptors for glutamate and GABA endure changes that lead to poorer functioning following a concussion (Atkins et al., 2009; Lowenstein et al., 1992). In addition, inflammatory changes have been shown to be triggered by mTBI or concussion, such that proinflammatory cytokines, or proteins that are released by immune cells to encourage inflammation, and activation of microglia may occur (Kelley et al., 2007).

In clinical settings, these biological mechanisms have been hypothesized to be related to concussive symptomology and neurocognitive changes following concussions. According to Giza and Hovda (2014), the physiological changes following a concussive brain injury that have been hypothesized to cause symptoms include the following:

- Ionic flux: the movement in and out of the cell which results in changes in electrostatic potentials following a concussion, hypothesized to relate to the symptoms of migraine headache and light and sound sensitivity.
- Energy crisis: the mismatched energy supply (cerebral blood flow) and demand (rapid use of ATP), hypothesized to lead to increased vulnerability to a second injury.
- Axonal injury and impaired neurotransmission: hypothesized to result in impaired cognition, slowed processing, and slowed reaction time following a concussive injury.
- Cell death: not always present following a concussion but hypothesized to cause chronic atrophy and the development of persistent impairments. Cell death is also the present hypothesis that explains the neurodegenerative disease chronic traumatic encephalopathy (CTE; Tharmaratamm et al., 2018).

Clinical Signs and Symptoms of Concussion

In most cases of concussion, a range of clinical signs and symptoms may occur which McCrory et al. (2017) describes may or may not include loss of consciousness, and must also not be better explained by drug, alcohol, prescribed medication use, other injuries (e.g., cervical injuries, peripheral vestibular dysfunction), or other comorbidities (e.g., psychological factors or coexisting medical conditions). The Center for Disease Control and Prevention (CDC) recognizes the most common immediate signs of concussion to include difficulty recalling events prior to or after the injury, appearing dazed or stunned, forgetting instructions or appearing confused, moving clumsily, losing consciousness, and mood, behavior, or personality changes. The most commonly reported symptoms of concussion include headache or “pressure” in the head, nausea or vomiting, balance problems or dizziness, double or blurry vision, sensitivity to light or noise, feeling sluggish, hazy, foggy, or groggy, confused, having decreased concentration, memory problems, and just not “feeling right” or “feeling down” (Center for Disease Control and Prevention, 2019).

Athletics and Concussions

One of the most common groups of individuals who experience concussions is athletes, likely due to the nature of physical contact within athletics. In the United States, it is estimated that approximately 1.6 to 3.8 million concussions occur due to sport-related injuries per year (University of Michigan Health, 2022), with contact or collision sports such as football, soccer, and hockey having higher prevalence rates (Ianof et al., 2014). Each year, nearly half a million college students in the National Collegiate Athletic Association (NCAA) participate in 24 different sports (NCAA, n.d.-b). Between the 2009-10 and 2014-2015 academic years, approximately 10,500 athletes in the NCAA were reported to have suffered concussions per year (NCAA, n.d.-a). In addition to playing sports, student-athletes are also simultaneously taking classes, which can be a complicating factor in terms of their recovery given the degree to which their symptoms might interfere with their academic performance (Wasserman et al., 2016).

The rate of concussions has increased dramatically in many sports over the past few decades, and although the sheer number of individuals participating in athletics has risen, it is also likely that this uprise is in part due to an increase in awareness surrounding concussions and concussion protocols (Daneschvar et al., 2011). Concussion protocols refer to agreed-upon plans for managing concussions that often include trained healthcare providers to implement individualized care plans in the event that a concussion is suspected (Vacher, 2019). In organized athletics, coaches are required to know the signs and symptoms of concussion, as well as report suspected head injuries to the appropriate healthcare providers in charge of concussion protocols. In fact, many states including Florida have adopted laws that require coaches to immediately remove athletes suspected of having a concussion, and in order to return to play, athletes must have written medical clearance (Athletic Coaches for Independent Sanctioning Authorities, 2021). The trained healthcare providers that oversee cases of concussion not only include medical doctors and athletic trainers but also include clinical neuropsychologists. In the past two decades, clinical neuropsychologists have played a key role in detecting concussions through neurocognitive assessments on the sidelines and in-office (Echemendia et al., 2011). Their expertise in recognizing cognitive, physical, emotional, and psychological changes renders them one of the most qualified professionals to assess concussion (Echemendia et al., 2009) also ensuring that athletes return to play safely.

Neurocognitive Assessment of Sport-Related Concussions

Neurocognitive assessment of concussion includes multiple steps and components, and since sport-related concussions (SRCs) involve many possible and varied symptoms from one individual to the next, the assessment also combines several tests measuring cognitive, physical, and emotional and psychological functioning. Cognitive assessment typically includes tests that measure memory, attention, concentration, processing speed, reaction time, and visuospatial capacity (Straus, 2013). Physical assessment often includes a self-report of physical symptoms experienced by the athlete which may include symptoms such as headache, visual problems, dizziness, noise/light sensitivity, nausea, and sleep difficulties (Johnson et al., 2011). In addition, assessing balance is a key component of assessing for concussions as it can provide information regarding the functioning of the sensorimotor systems (Johnston et al., 2017). Emotional and psychological functioning is also assessed by self-report from the athlete and typically targets the level of emotionality, sadness, nervousness or anxiety, and irritability an athlete may be experiencing (Johnson et al., 2011).

Timeline of Assessment

When an athlete is suspected of a SRC, the timeline of neurocognitive assessment typically includes at least three separate testing sessions: baseline, immediate post-injury, and follow-up. Baseline testing, completed prior to a concussive injury, provides an accurate measure of an athlete's premorbid neurocognitive functioning and symptom status which can help support return-to-play decisions (Johnson et al., 2011). Following a head injury or suspicion of SRC, it is recommended that athletes are assessed within 72 hours of their injury and their neurocognitive performance, as well as symptomology, are compared to their baseline functioning (Johnson et al., 2011). According to Barr and McCrea (2002), athletes with suspected concussions often show detectable decline on neurocognitive testing in the initial hours, days, and potentially even weeks following their injury. In addition, neurocognitive testing may show a decline in executive functioning, learning and memory, and attention and processing speed domains which can be detected in the early phases post-injury (McInnes et al., 2017). Therefore, if an athlete demonstrates a decline in neurocognitive functioning following a suspected concussion, a concussion may be diagnosed. In order to return to play, the athlete typically undergoes another round of neurocognitive testing (i.e., follow-up) at the recommendation of the neuropsychologist, or once the athlete's symptoms have subsided (Scolaro-Moser et al., 2007). Lastly, a physical exertion protocol is used to ensure that the athlete's concussive symptoms do not return with gradually increased intensity of physical activity (Quatman-Yates et al., 2017). According to McCrory et al. (2017), return-to-play criteria have been agreed upon internationally to include the following list of requirements: the athlete must be asymptomatic at rest, the athlete must be asymptomatic with full physical and cognitive exertion, balance testing must be returned to baseline, and neurocognitive performance must be returned to baseline.

Importance of Athletes' History

Another important aspect of concussion protocols and neurocognitive testing is obtaining information regarding the athlete's prior history and background, including medical, social, psychiatric/psychological, academic, cultural, behavioral, and developmental history. The athlete's susceptibility to concussion and potential complicating factors may differ based on pre-existing conditions such as headache, migraine, depression and/or other mental health disorders, attention-deficit hyperactivity disorder (ADHD) or attention deficit disorder (ADD), or motion sickness (Cottle et al., 2017). Also included in the medical history is a thorough examination of any previous head injuries and concussions, since repeated head injuries have been shown to result in longer recovery, more severe symptoms, and increase susceptibility to having another concussion (Center for Disease Control and Prevention & National Center for Injury Prevention and Control, 2021).

Pre-existing Headache Disorder

As noted above, many individuals experience headaches even without a history of head injury or concussion. Meanwhile, despite migraine or severe headache disorders affecting roughly 1 out of 6 Americans (Burch et al., 2018), the relationship between pre-existing headache and/or migraine and neurocognitive testing for sport-related concussion has been of little focus in research settings. Nearly 50% of the adult global population experiences any type of headache disorder or headache condition (e.g., migraines, tension headaches, headaches related to trauma, cluster headaches, etc.), with over 30% of those individuals reporting migraine (World Health Organization: WHO, 2016). Headache disorders are characterized by recurrent pain in the head or facial area that can be throbbing, sharp, or dull (Cleveland Clinic, 2020a). Migraine headaches result in more severe symptoms, lasting anywhere from four hours to several days, and include intense pain that may be located on one or both sides of the head, nausea and/or vomiting, and sensitivity to light and/or noise (AMF Editorial Board, 2018).

Pathophysiology of Headaches and Migraines

The pathophysiology of migraine is often viewed in four separate phases including the premonitory, aura, headache, and postdrome phases, which often occur in that order, however, there tends to be some overlap, with some symptoms occurring in multiple phases (Goadsby et al., 2017). The first phase, the premonitory phase, precedes the head pain by up to 72 hours and often includes changes in mood, activity, irritability, fatigue, food cravings, repetitive yawning, stiff neck, and phonophobia, ending within two hours of head pain (Giffin et al., 2003). These symptoms have been hypothesized to relate to the functioning of the hypothalamus, as imaging studies have shown an increase in blood flow to this region during the premonitory phase (Maniyar et al., 2014).

The next phase, the aura phase, is experienced by approximately one-third of individuals who have migraines and can be defined as a fully reversible neurological deficit with one or more transient features, with at least one of those features having unilateral localization, developing over five or more minutes and lasting between five to 60 minutes (ICHD-3). These symptoms are often visual in nature but can affect sensory, motor, speech, brain stem, and retinal areas, as well (Goadsby et al., 2017). The aura phase also commonly overlaps with the proceeding phases (Hansen et al., 2012). The pathophysiology of the aura phase is hypothesized to stem from a temporary flood of neuronal depolarization of the cortex, which affects retinotopic propagation on the visual cortex and therefore causes a visual aura (Charles, 2013).

The following phase, the headache phase, is defined by the ICHD-3 as a headache attack lasting four to 72 hours and is accompanied by the following symptoms, nausea, photophobia and phonophobia, or both. The headache is described as unilateral, pulsating, of moderate or severe intensity, and is exasperated by physical activity, and meeting two of these characteristics fulfills the diagnostic criteria (Goadsby et al., 2017). The pathophysiology of the headache phase concerns the trigeminovascular pathway, which conveys nociceptive information from the meninges to the central areas of the brain, as well as the cortex (Messlinger et al., 2011). Migraine pain begins when nociceptive neurons that excite the dura mater are stimulated and vasoactive neuropeptides (e.g., calcitonin gene-related peptide; CGRP, pituitary adenylate cyclase-activating polypeptide-38) signal the trigeminovascular pathway (Amin et al., 2014). The vasoactive neuropeptides hypothesized to activate meningeal nociceptors with ATP, glutamate, potassium, hydrogen ions, CGRP, and nitrous oxide release locally (Dodick, 2018). Following the release, signals are transmitted to areas of the brain including the brainstem, thalamic, hypothalamic, and basal ganglia nuclei which then project to multiple cortical areas leading to the phenotypic expression of migraine pain and the associated symptoms (Dodick, 2018).

The final phase, the postdrome has been largely neglected in literature, including the ICHD-3 lacking a definition of postdrome in migraine (Goadsby et al., 2017). Despite this, some studies have found this phase to have several similar symptoms as the premonitory phase, such as tiredness, difficulty concentrating, and neck stiffness; however, it is unsure whether these symptoms reoccur or if they persist throughout the entirety of the attack (Giffin et al., 2016; Blau, 1991; Kelman, 2006; Judit et al., 2000). The physiology of the postdrome phase involves dysfunction of diencephalic and brainstem centers, including the pontine and midbrain structures, which have altered function during and after the headache phase (Giffin et al., 2016).

Primary, Secondary, and Neuropathies/Facial Pain/Other Headaches

According to the International Classification of Headache Disorders-3 (International Headache Society, 2013), headache disorders can be classified into three separate categories including primary headaches, secondary headaches, and neuropathies/facial pain/other headaches. The primary headaches include migraine, tension-type headache (TTH), trigeminal autonomic cephalalgias (TACs; e.g., cluster headache), and other primary headaches (e.g., cold-stimulus headache, exercise headache). Secondary headaches include headache attributed to trauma or injury to the head and/or neck, cranial or cervical vascular disorder, non-vascular intracranial disorder, a substance or withdrawal, infection, disorder of homeostasis, disorder of the cranium, neck, eyes, ears, nose, sinuses, teeth, mouth, or other facial or cervical structure, and psychiatric disorders. Examples of secondary headaches include headaches due to whiplash, headaches due to cerebral ischemic events, and headaches due to increased cerebrospinal fluid pressure. Neuropathies/facial pain/other headaches include painful lesions of the cranial nerves and facial pain, as well as other headache disorders, which may be diagnosed based on the inability to fulfill criteria for a certain type of headache. Each classification may be further clarified based on specific symptomology, such as frequency and length of attacks, presence of aura, unilateral/bilateral pain, etc. Although the International Headache Society (2013) has a classification system for headache disorders, for the purpose of this study, a simplified format was used including whether participants reported a diagnosis or treatment of any types of headaches.

Headache Disorder vs. Post-Concussive Headache

Headache is the most commonly reported symptom of concussion (Cleveland Clinic, 2020b) therefore, a comparison of pre-existing headaches to post-injury headaches is necessary to help clarify whether an athlete has suffered a concussion. When gathering a background from an athlete, collecting thorough information regarding the presentation of each headache should include how often they experience headaches, the severity, location, and type of pain, and any medication usage, including its effectiveness. According to the International Headache Society (2013), three possible outcomes are considered when primary headaches become worse after a head injury, including coincidence, aggravation of the primary headache, or a new headache, such as posttraumatic headache (PTH). Oftentimes, the neuropsychologist or other healthcare provider will need to investigate these options to determine whether an athlete is experiencing a headache related to a previous condition or whether it may be related to a concussion. Unfortunately, there are no specific headache features known to differentiate between PTH and primary headaches such as migraine or TTH, but many times, the amount of time that elapsed between a head injury and development of a headache is used as a tool to help distinguish the two (International Headache Society, 2013). In addition, changes in balance and neurocognitive impairment as well as other symptoms such as dizziness, fatigue, difficulty concentrating, psychomotor slowing, mild memory problems, insomnia, anxiety, personality changes, and irritability may be used as supplemental factors in determining whether a concussion is contributing to a headache (International Headache Society, 2013). Furthermore, in most cases of PTH, the headaches eventually resolve on their own, whereas in primary headache disorders, such as migraine, they do not (Inserro, 2020). Also, in cases where PTH does not go away on its own, it typically does not respond to migraine medication (Inserro, 2020). Although many headaches may seem very similar, these factors can help determine whether a headache is due to a concussion or pre-existing disorder.

Neurocognitive Findings of Headache and/or Migraine

In the research field, neurocognitive studies of headache and/or migraine have shown largely inconsistent results; nonetheless, a number of studies lean toward migraineurs experiencing some subtle deficits in verbal and visual memory and executive processing (O’Bryant et al., 2006). However, many studies include participants seeking medical treatment for their migraines, suggesting that their headache condition may be more severe, which may also be contributing to the significance of neuropsychological impairment in these populations (O'Bryant et al., 2006). Nevertheless, when exploring a specific subtype of migraine referred to as migraine with aura, multiple studies (e.g., Le Pira et al., 2000; Mulder et al., 1999; Hooker and Raskin, 1986) found that individuals who experience these migraines exhibited significantly worse neurocognitive performance in domains such as immediate and delayed recall, selective attention, information processing, and psychomotor speed. Meanwhile, other studies (e.g., Burker et al., 1989; Bell et al., 1999; Leijdekkers et al., 1990) have found no significant differences between migraine and non-headache pain suffers in cognitive domains including memory, attention and processing speed, executive functioning, visuospatial functioning, and psychological symptomology. Altogether, research on differences in cognitive functioning between those with and without headache appears to be mixed.

Neurocognitive Performance in Concussed Athletes with Headache Disorder

Previous research investigating neurocognitive performance among athletes with a pre-injury history of headache and/or migraine and suspicion of concussion also contains inconsistent findings. In some cases, there have been significant differences between athletes with a history of migraine and those without. For example, Terry, Reddi, et al. (2019) found that athletes with a pre-injury history of migraine show greater symptom severity at baseline and after a suspected injury, including a greater likelihood of experiencing mental fogginess and memory problems acutely after a concussive injury. Furthermore, Covassin et al. (2014) described that concussed athletes with a pre-injury history of migraine show greater symptom severity pertaining to migraine, cognitive, fatigue, and somatic questions. It is also of note that some athletes with a pre-injury migraine history are at risk for prolonged recovery and delay in returning to school, as Terry and Huebschmann et al. (2019) found a significantly lower percentage of high school and collegiate female athletes with migraine histories who sustained concussions returned to school at 7 days, 14 days, and 21 days post-injury compared to women without migraine histories. Another important aspect to consider is the prevalence of migraines across males and females, as migraine is reported to be two-to-three times more prevalent in females than males, in addition to a three- to four-fold prevalence in females following puberty compared to males (Al-Hassany et al., 2020). Thus, the difference between sexes found by Terry and Huebschmann et al. (2019) could relate to the fact that migraines are more common in females or that the sample of males with a history of migraine was significantly smaller than females (12.8% females and 6.6% males).

Meanwhile, research has also suggested that athletes with a history of pre-injury migraine did not show any greater neurocognitive decline after a concussion compared to athletes without a history of pre-injury migraine (Covassin et al., 2014). In addition, Register-Mihalik et al. (2007) found no significant effects of headache on the Balance Error Scoring System (BESS) at baseline. Furthermore, concussed athletes who self-report a pre-injury history of migraine showed no differences in recovery time (Covassin et al., 2014). Similarly, Putukian et al. (2021) found that headache history was not significantly associated with length of recovery time and days until full return to play. All in all, research on the impact of pre-existing headache on post-injury symptoms and recovery from concussions also appears to be somewhat mixed.

Rationale

Given mixed results of relatively sparse studies exploring the degree to which pre-existing headaches complicate concussion severity and recovery, additional research in this area appears warranted. The present research study aims to better understand the impact pre-existing headaches have on concussion severity and recovery, which may allow for a better determination of specific recommendations and referrals, as well as provision of tailored accommodations to athletes. Specifically, knowing whether individuals with prior headaches or migraines tend to be more likely to experience more severe symptoms, greater cognitive impairment, and/or a longer recovery following a concussion has important implications for the initial diagnosis and management of concussions in this subpopulation. Greater effort could be undertaken to treat or manage headache symptoms, such as referral to a neurologist for co-management of a headache condition, and implementation of academic accommodations to reduce the impact of headache symptoms on grades may be appropriate. Education regarding the potential for more severe symptoms and prolonged recovery can also be provided so the individual knows what to expect and may be less likely to experience frustration if recovery seems to be taking longer compared to others without a headache history. Altogether, the present study addressed many of these concepts and therefore fills important gaps in the current literature.

Chapter 3: Objectives

The present study aimed to investigate the relationship between pre-existing headache and/or migraine and neurocognitive assessment of concussion. Specifically, the following objectives and hypothesis were proposed:

Objective 1: To determine whether student-athletes with history of headache and/or migraine will perform differently on baseline symptoms, and memory and psychomotor speed tasks.

Hypothesis 1.1: Student-athletes with a history of headache and/or migraine will self-report more symptoms and greater severity of symptoms at baseline testing compared to student-athletes without a history of headache and/or migraine.

Hypothesis 1.2: Student-athletes with a history of headache and/or migraine will demonstrate worse performance in verbal and visual memory at baseline on ImPACT and SCAT-5 testing compared to student-athletes without a history of headache and/or migraine.

Hypothesis 1.3: Student-athletes with a history of headache and/or migraine will demonstrate worse performance in psychomotor speed on ImPACT at baseline testing compared to student-athletes without a history of headache and/or migraine.

Objective 2: To determine whether student-athletes with a history of headache and/or migraine will experience greater symptoms following a concussion.

Hypothesis 2.1: Student-athletes with a history of headache and/or migraine will report more symptoms and greater severity of symptoms following a concussion compared to student-athletes without a history of headache and/or migraine.

Objective 3: To determine whether student-athletes with a history of headache and/or migraine have a history of longer recovery following a prior concussion.

Hypothesis 3.1: Student-athletes with a history of headache and/or migraine will have a history of longer recovery following a suspected concussion compared to student-athletes without a history of headache and/or migraine.

Chapter 4: Methods

Participants

An overall total of 1206 athletes were tested between the 2017-2022 athletic seasons. Out of the 1206 athletes, 77 were excluded due to inaccurate or incomplete data collection and/or entry. After removing these athletes, a total of 1129 NCAA Division II college athletes were included in the present study. Among the entire sample 65.1% identified as male and 34.9% identified as female. Additionally, 104 of the 1129 athletes were evaluated for concussion and matched to their respective baseline evaluation, with 59.6% of those athletes identifying as male and 40.4% identifying as female. Out of the 104 athletes evaluated for concussion, 10 athletes identified a history of headache and/or migraine. Follow-up evaluations related to concussion recovery length were excluded from analysis. Athletes were removed from the sample with incomplete or missing data which resulted in an insufficient sample size in the headache disorder group (n = 2). Athletes in the headache disorder group comprised of 12.8% of the entire sample (N = 144) while athletes in the non-headache disorder made up 87.2% (N = 985) of the sample. The average education level was 13.47 years (SD = 2.24) for the headache disorder group and 13.73 years (SD = 1.41) for the non-headache disorder group. Among the 1129 athletes, many of them identified as being Caucasian/White (69.6%), with the remaining athletes identifying as African American/Black (14.1%), Native Hawaiian/Other Pacific

Islander (0.5%), Asian (1.2%), Hispanic/Latino (7.3%), American Indian/Alaska Native (0.4%), and two or more races (6.9%). Athletes average age was 19.89 years (*SD* = 1.71). Athletes' sports within the sample included football (19.2%), men's lacrosse (11.0%), baseball (6.5%), men's rowing (6.0%), men's swimming (5.8%), women's soccer (5.4%), cheer/dance (5.3%), men's soccer (5.0%), women's lacrosse (5.0%), softball (3.6%), women's rowing (3.5%), women's swimming (3.3%), men's golf (3.2%), volleyball (3.2%), women's basketball (3.1%), men's basketball (2.9%), men's cross country (2.1%), men's tennis (1.8%), women's cross country (1.2%), men's track and field (0.8%), women's golf (0.7%), women's tennis (0.7%), and women's track and field (0.6%). Of the 1129 athletes, the vast majority reported no history of concussion (77.7%), while the remaining reported experiencing at least one concussion in their lifetime (22.3%). All athletes attended the Florida Institute of Technology and completed baseline testing in order to participate in their sport. Baseline and post-trauma evaluations included measures of neurocognitive function, self-reported symptoms, balance, effort, and mood. All post-trauma evaluations occurred within approximately 72 hours of each athlete's reported injury.

Questions from two separate assessments were used to determine whether athletes have a headache disorder or history of headache and/or migraine. On Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), athletes indicated whether they were treated for headaches or migraine headaches by a physician. On the Sports Concussion Assessment Tool – 5th Edition (SCAT-5), athletes indicated whether they were diagnosed and/or treated for a headache disorder or migraine. Athletes who endorsed either or both questions pertaining to diagnosis or treatment of headache disorder and/or migraine at baseline were included in the headache group, which resulted in a sample size of 10. All participants signed a consent form to participate in research through the Florida Tech Concussion Management Program.

Measures

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

ImPACT is a neurocognitive test that is administered using a computer. Within ImPACT, four core cognitive domains are assessed and include verbal memory, visual memory, visual motor speed, and reaction time. These domains are comprised of six cognitive subtests: word memory, design memory, X's and O's, symbol match, color match, and three letters. In addition to cognitive testing, athletes are asked to report symptoms through an inventory containing 22 common symptoms of concussion and report demographic information such as history of concussions and headaches or migraines, as well as other neurodevelopmental conditions including ADHD and learning disability.

Word Memory. Word memory assesses attentional processes and verbal recognition memory (Lovell, 2005). Athletes are presented 12 target words twice and subsequently asked to recognize the target words in a 24-word list. In addition, a delay condition is added approximately 20 minutes later where athletes are again asked to identify the 12 target words from another 24-word list.

Design Memory. Design memory also evaluates attentional processes along with visual recognition memory. Similar to word memory, athletes are presented with 12 target designs twice and subsequently asked to recognize the initial target designs from

24 designs. The designs presented are not typical geometric figures. Twenty minutes later, athletes are asked to recognize the 12 target designs again.

X's and O's. The X's and O's subtest assesses visual working memory, visual processing, and visual-motor speed. Two components make up this subtest, including a reaction-time-based distractor task and a visual memory task. In the reaction-time component, athletes are presented with either a red circle or blue square. They are then instructed to press a key on the keyboard specific to each stimulus. Following this, the visual memory task is presented and is made up of several X's and O's spread randomly across the screen. Three of the X's and O's are highlighted and the athlete is asked to remember their location. The athlete is then asked to complete the reaction-time distractor task again. Subsequent to the distractor task, the athlete is presented with the spread of X's and O's and asked to select the location of the X's and O's that were previously highlighted. This sequence is repeated four times.

Symbol Match. Symbol match assesses visual processing speed, learning, and memory. Athletes are first presented with a screen that displays common symbols such as a triangle, square, arrow, etc. Directly below each symbol is a number from one to nine. One at a time, a symbol is presented and the athlete is instructed to click the matching number as quickly as possible. Performance is reinforced through the illumination of a correctly clicked number in green and incorrect performance in red. Following the completion of 27 trials, the symbols are removed from the top grid and the athlete is asked to recall from memory which number corresponds to which symbol.

Color Match. Color match measures reaction time and impulse control. The athlete is required to respond by clicking on a red, blue, or green button as they are presented on the screen to ensure the following trials would not be affected by color blindness. Next, word names are displayed on the screen in the same color as the word (e.g., RED) or in a different color (GREEN or BLUE). The athlete is instructed to click in the box as quickly as possible only if the word name is presented in the matching color.

Three Letters. Three letters measures working memory and visual-motor response speed. Athletes begin by practicing a distractor task that consists of numbers 1 through 25 randomly displayed on a five-by-five grid. They are instructed to click as quickly as possible on the numbered buttons in a backward order, starting with the number 25. The position of the numbers is randomized after each trial to minimize practice effects. Following this task, the athlete is presented with three consonants displayed on the screen. Immediately after the letters are displayed, the numbered grid re-appears, and they are instructed to click the numbers in a backward order again. After 18 seconds, the grid disappears, and the athlete is asked to recall the three letters by typing them on the keyboard. This sequence is repeated for five trials.

Symptom Inventory. The symptom inventory allows the examiner to determine whether the athlete is experiencing symptoms that are characteristic of a concussion. The list includes 22 common concussion symptoms that are each rated 0 through 6 based on severity, with 6 as most severe. The symptoms depict cognitive, somatic, emotional, or sleep symptoms of concussion and include the following list: Headache, Trouble Falling Asleep, Nausea, Sleeping More than Usual, Vomiting, Sleeping Less than Usual, Balance Problems, Drowsiness, Dizziness, Sensitivity to Light, Sensitivity to Noise, Irritability, Feeling Mentally Foggy, Sadness, Difficulty Concentrating, Nervousness, Difficulty

Remembering, Feeling More Emotional, Visual Problems, Numbness or Tingling, Feeling Slowed Down, and Fatigue.

Demographics. The demographic questionnaire asks the athlete to report basic information pertaining to their physical makeup, background, concussion and medical history, and sport. The questionnaire includes Date of Birth, First Name, Last Name, Height, Weight, Gender, Handedness, Native Country, Native Language, Second Language (if fluent), Ethnicity, Years of Education Completed, History of Speech/Learning Disability, Sport, Position in Sport, Years of Experience at Current Level, Number of Times Diagnosed with a Concussion, Most Recent Concussions, Treatment by Physician for headaches, migraine headaches, epilepsy/seizures, brain surgery, meningitis, substance/alcohol, or psychiatric conditions. As noted above, if an athlete indicates he/she/they have been treated by a physician for headaches or migraine headaches, they will be included in the headache group.

Sports Concussion Assessment Tool - 5th Edition (SCAT-5)

The SCAT-5 is a standardized tool used by physicians and licensed healthcare professionals to evaluate concussions based on cognitive, symptom, and balance tests (Echemendia et al., 2017). An on-field and off-field assessment are included in the SCAT-5. The Immediate or On-Field Assessment section includes information regarding Red Flags pertaining to head injuries, Observable Signs of Concussions, a brief Memory Assessment (Maddocks Questions), an examination with the Glasgow Coma Scale (GCS), and a Cervical Spine Assessment. The Office or Off-Field Assessment is made up of six steps, including Athlete Background, Symptom Evaluation, Cognitive Screening, Neurological Screen, including an assessment of balance, Delayed Recall, and Decision.

Athlete Background. The athlete background section includes demographic information pertaining to the athlete's medical history and makeup. Information such as sport, team, school, date/time of injury, years of education completed, age, gender, dominant hand, history of concussions, and medical history is included. Athletes reporting a history of suspected concussion also reported recovery length for the most recent concussion, which was used in later analyses determining history of recovery length following a suspected concussion. Questions referring to medical history include identifying whether the athlete has ever been hospitalized for a head injury, diagnosed/treated for headache disorder or migraine, or diagnosed with a learning disability/dyslexia, Attention-Deficit Disorder (ADD)/Attention-Deficit Hyperactivity Disorder (ADHD), and psychiatric disorders. The athlete is also asked to report their current medications. As noted above, athletes who indicate having a diagnosis or treatment for a headache disorder or migraine will be included in the headache group.

Symptom Evaluation. The symptom evaluation section includes a list of 22 symptoms characteristic of concussion with a severity rating scale from zero (none) to six (severe). The athlete is asked to read an instruction paragraph out loud then complete the symptom scale. The symptom scale includes the following symptoms: Headache, "Pressure in head," Neck pain, Nausea or vomiting, Dizziness, Blurred vision, Balance problems, Sensitivity to light, Sensitivity to noise, Feeling slowed down, Feeling like "in a fog," "Don't feel right," Difficulty concentrating, Difficulty remembering, Fatigue or low energy, Confusion, Drowsiness, More emotional, Irritability, Sadness, Nervous or Anxious, and Trouble falling asleep (if applicable). The athlete is also asked to report whether their symptoms get worse with physical or mental activity, and report what percent of normal they feel.

Cognitive Screening. The cognitive screening section measures orientation, immediate memory, and concentration. For the orientation section, the athlete is asked to report the month, date, day of the week, year, and time. In the immediate memory section, the examiner reads a list of 10 words, and the athlete is asked to immediately recall as many words as they remember. This is repeated for three trials. For examining concentration, digits backwards and months in reverse order are used. For digits backwards, the examiner reads a string of numbers and the athlete is asked to immediately repeat them back in reverse order of how they were read. The digit spans increase every two trials. This is repeated eight times or until the athlete fails two consecutive trials with the same digit span. For months in reverse order, the athlete is asked to state the months in the reverse order.

Neurological Screen. The neurological screen section includes questions pertaining to the athlete's ability to read, range of motion, movement and double vision, hand-eye coordination, and tandem gait. In addition to tandem gait, the athlete's balance is examined using the Modified Balance Error Scoring System (mBESS), which consists of a series of stances including double leg, single leg (non-dominant foot), and tandem stance (non-dominant foot in back). The athlete is asked to remain in each stance for 20 seconds with the examiner counting the number of errors.

Delayed Recall. The delayed recall section is performed five minutes after the end of the Immediate Recall section and the athlete is asked to recall as many words from the previous 10-word list as they can remember, in any order.

Decision. The decision section includes a tally of scores from the previous five sections to help determine a diagnosis.

Procedure

Archival data was used, and all athletes received the specific test battery and test sessions outlined below. Athletes were administered the ImPACT, SCAT-5, DCT, A-Test, PHQ-9, GAD-7, and Grit Scale at baseline and post-trauma. Baseline testing was performed before the fall athletic season and post-trauma evaluations were completed within approximately 72 hours of the athlete's injury.

For baseline testing, athletes were scheduled in large groups according to their respective sports. Each group was split randomly into two smaller groups; one group completed the computerized ImPACT first and the other group completed the paper testing first (SCAT-5, DCT, A-Test, PHQ-9, GAD-7, and Grit Scale) before switching.

At post-trauma, the athletes were scheduled within approximately 72 hours of their injury and a clinical interview was completed to obtain the details surrounding the injury. The clinical interview included questions pertaining to the timeline of the injury (date, time, location), a description of the event, mechanism of injury, symptoms within the last 72 hours, medications, appetite, activities, sleep, alcohol/drug use, mental and physical activity, previous head injuries, and history of headache and/or migraine. Following the interview, the athletes were given the same paper testing as baseline (SCAT-5, DCT, A-Test, PHQ-9, GAD-7, and Grit Scale) and alternate forms were used if available to reduce practice effects. The athletes were then given the ImPACT post-injury test and a different randomized version of the test was given (e.g., Post-Injury 1, Post-

Injury 2, etc.). Following the evaluation, the supervising neuropsychologist reviewed the findings and determined whether there was suspicion of concussion or not.

Data Analysis

Prior to analyzing data, approval from the Florida Institute of Technology Institutional Review Board (IRB) was obtained by the researcher. Data was analyzed using IBM Statistical Package for the Social Sciences version 28 (SPSS-28). Mean, median, and standard deviation values of the neurocognitive assessment battery test scores are presented to help establish comparisons between pre-injury headache disorder groups and athletes without pre-injury headache disorder. Additionally, most recent suspected concussion recovery time was used coded based on self-reported length of recovery (0 = No history of concussion; 1 = < 1 week; 2 = 1 week; 3 = 1-2 weeks; 4 = 2-3 weeks; 5 = 3-4 weeks; 6 = 1 month; 7 = 1-2 months; 8 = 2-3 months; 9 = 3 to 4 months; 10 = 4-5 months; 11 = 5-6 months; 12 = >12 months; 13 = Unknown).

Paired sample t-tests and Mann-Whitney U tests were used to compare baseline symptoms, severity of symptoms, verbal and visual memory and psychomotor speed between pre-injury headache disorder athletes and athletes without pre-injury headache disorder. An independent samples t-test was conducted to compared recovery length between pre-injury headache disorder athletes and athletes without pre-injury headache disorder. Analysis of covariance (ANCOVA) tests were also used to determine the effect of athletes with pre-injury headache disorder and athletes without pre-injury headache disorder on post-trauma total symptom and symptom severity scores, after controlling for individual baselines.

An *a priori* power analysis was conducted using G*Power version 3.1.97 (Faul et al., 2007) to determine the minimum sample size required to test the study hypothesis. Results indicated the required sample size to achieve 80% power for detecting a medium effect, at a significance criterion of $\alpha = .05$, was $N = 134$ for Mann-Whitney U tests. Additionally, the required sample size to achieve 80% power for detecting a medium effect, at a significance criterion of $\alpha = .05$, was $N = 34$ for ANCOVA tests. Lastly, the required sample size to achieve 80% power for detecting a medium effect, at a significance criterion of $\alpha = .05$, was $N = 64$ for independent sample t-tests. Thus, the obtained sample size of $N = 1129$ and $N = 144$ for the headache group is adequate to test the study hypotheses.

Chapter 5: Results

Data was obtained for the total symptoms, severity, immediate memory, and delayed memory subtests of the SCAT-5. Verbal and visual memory composite scores were also obtained from the ImPACT, as well as reaction time. Recovery length of most recent suspected concussion and history of headache and/or migraine were obtained from the athlete's demographic questionnaires at baseline.

Statistical Analyses

Normative Data. A one-way ANOVA was calculated to determine whether there were any significant effects of gender, age, education, and reported medication usage between the headache history and non-headache history groups. The one-way ANOVA revealed there was a significant effect of gender [$F(1,1127) = 11.123$, $p < .001$] between the headache and non-headache groups, such that more male athletes ($n = 76$) reported a history of headache and/or migraine compared to females ($n = 68$). Additionally, there was a significant effect of age [*F*(1,1127) = 5.967, *p* = .015] between the headache and non-headache groups, such that athletes with a headache history were significantly younger (*M* = 19.57) than athletes with no headache history (*M* = 19.94). Furthermore, there was a significant effect of education [*F*(1,1127) = 4.400, *p* = .036] between the headache and non-headache groups, such that athletes with a headache history reported lower education (*M* = 13.47) than athletes with no headache history (*M* = 13.73). Lastly, reported medication usage [*F*(1,1127) = 9.276, *p* = .002] among the two headache disorder groups was significantly different, such that athletes with a headache history were more likely to report taking medications compared to athletes without a headache history. See Table 1 for a full description of athlete demographic information.

Baseline Symptoms and Severity. A Mann-Whitney U test was calculated to determine whether there were differences in baseline SCAT-5 total symptom scores reported between athletes with a headache history (*N* = 144) and athletes with no headache history (*N* = 985). Distributions of the SCAT-5 total symptom scores were not similar, as assessed by visual inspection. In support of hypothesis 1.1, baseline SCAT-5 total symptom scores for athletes with a headache history (*Mdn* = 4.00; *mean* rank = 762.88) were statistically significantly higher than for athletes with no headache history (*Mdn* = 1.00; mean rank = 536.07), *U* = 99414.50, *z* = 8.09, *p* < .001.

As a follow-up, a second Mann-Whitney U test was calculated to determine whether there were differences in SCAT-5 headache-specific symptom scores reported between athletes with a headache history (*N* = 144) and athletes with no headache history (*N* = 985). Distributions of the SCAT-5 headache symptom scores were not similar, as assessed by visual inspection. In support of hypothesis 1.1, baseline SCAT-5 headache symptom scores for athletes with a headache history (*Mdn* = 1.00; mean rank = 762.22) were statistically significantly higher than for athletes with no headache history (*Mdn* = 0.00; mean rank = 536.17), $U = 99319.50$, $z = 10.80$, $p < .001$.

A Mann-Whitney U test was also calculated to determine whether there were differences in SCAT-5 symptom severity scores reported between athletes with a headache history ($N = 144$) and athletes with no headache history ($N = 985$). Distributions of the SCAT-5 symptom severity scores were not similar, as assessed by visual inspection. Baseline SCAT-5 symptom severity scores for athletes with a headache history (*Mdn* = 4.50; mean rank = 768.45) were statistically significantly higher than for athletes with no headache history (*Mdn* = 1.00; mean rank = 535.26), $U = 100217.00$, $z = 8.30$, $p < .001$, in support of hypothesis 1.1. See Table 2 for a comparison of baseline symptom and severity scores amongst athletes with and without a headache history.

Verbal and Visual Memory. A Mann-Whitney U test was calculated to determine whether there were differences in baseline ImPACT Verbal Memory Composite scores reported between athletes with a headache history ($N = 144$) and athletes with no headache history ($N = 985$). Distributions of the ImPACT Verbal Memory Composite scores were not similar, as assessed by visual inspection. Baseline ImPACT Verbal Memory Composite scores for athletes with a headache history (*Mdn* = 91.00; mean rank = 534.97) were not statistically significantly lower than for athletes with no headache history (*Mdn* = 91.00; mean rank = 569.39), $U = 66596.00$, $z = -1.19$, $p = .236$, failing to support hypothesis 1.2.

A second Mann-Whitney U test was calculated to determine whether there were differences in baseline ImPACT Visual Memory Composite scores reported between athletes with a headache history (*N* = 144) and athletes with no headache history (*N* = 985). Distributions of the ImPACT Visual Memory Composite scores were not similar, as assessed by visual inspection. In partial support of hypothesis 1.2, baseline ImPACT Visual Memory Composite scores for athletes with a headache history (*Mdn* = 79.00; mean rank = 514.91) were statistically significantly lower than for athletes with no headache history (*Mdn* = 82.00; mean rank = 572.32), *U* = 63707.50, *z* = -1.97, *p* = .048. See Figure 1 for a comparison of ImPACT Visual Memory Composite scores amongst athletes with and without a headache history.

A third Mann-Whitney U test was calculated to determine whether there were differences in baseline SCAT-5 Immediate Memory scores reported between athletes with a headache history (*N* = 144) and athletes with no headache history (*N* = 985). Distributions of the SCAT-5 Immediate Memory scores were not similar, as assessed by visual inspection. Baseline SCAT-5 Immediate Memory scores for athletes with a headache history (*Mdn* = 21.00; mean rank = 563.42) and athletes with no headache history (*Mdn* = 21.00; mean rank = 575.78) were not statistically significantly different, *U* = 742472.00, *z* = 0.43, *p* = .670, failing to support hypothesis 1.2.

A fourth Mann-Whitney U test was calculated to determine whether there were differences in baseline SCAT-5 Delayed Memory scores reported between athletes with a headache history (*N* = 144) and athletes with no headache history (*N* = 985). Distributions of the SCAT-5 Delayed Memory scores were not similar, as assessed by visual inspection. Baseline SCAT-5 Delayed Memory scores for athletes with a headache history (*Mdn* = 7.00; mean rank = 568.39) and athletes with no headache history (*Mdn* = 7.00; mean rank = 541.84) were not statistically significantly different, *U* = 67585.50, *z* =

-0.93, p = .356, failing to support hypothesis 1.2. See Table 2 for a comparison of baseline verbal and visual memory scores amongst athletes with and without a headache history.

Psychomotor Speed. A Mann-Whitney U test was calculated to determine whether there were differences in baseline ImPACT Visual Motor Composite scores reported between athletes with a headache history (N = 144) and athletes with no headache history (N = 985). Distributions of the ImPACT Visual Motor Composite scores were not similar, as assessed by visual inspection. Baseline ImPACT Visual Motor Composite scores for athletes with a headache history (*Mdn* = 41.67; mean rank = 494.34) were statistically significantly lower than for athletes with no headache history (*Mdn* = 43.75; mean rank = 575.33), U = 60745.50, z = -2.78, p < .005, supporting hypothesis 1.3.

An additional Mann-Whitney U test was calculated to determine whether there were differences in baseline ImPACT Reaction Time Composite scores reported between athletes with a headache history (N = 144) and athletes with no headache history (N = 985). Distributions of the ImPACT Reaction Time Composite scores were not similar, as assessed by visual inspection. Baseline ImPACT Reaction Time Composite scores for athletes with a headache history (*Mdn* = 0.59; mean rank = 615.59) were statistically significantly higher than for athletes with no headache history (*Mdn* = 0.57; mean rank = 557.60), U = 78205.00, z = 2.00, p = .046, supporting hypothesis 1.3. As a reminder, higher scores on this variable suggest slower/poorer performance. See Table 2 and Figure 2 for a comparison of psychomotor speed scores amongst athletes with and without a headache history.

Change Between Baseline and Post-Trauma Symptoms and Severity. A paired-samples t-test was calculated amongst total symptom scores at baseline and post-trauma for the sample of athletes who underwent concussion evaluations and thus have both baseline and post-trauma measurements (*n* = 104) in an attempt to compare whether significant differences could be detected from baseline to post-trauma, regardless of headache history. Specifically, a paired-samples t-test was conducted to determine whether there was a statistically significant mean difference between athletes' total symptom scores at baseline (*n* = 104) and post-trauma (*n* = 104) following a concussion. No outliers were detected, as inspected on a boxplot. The assumption of normality was not violated, as assessed by skewness and kurtosis values. As expected, athletes reported more symptoms following a concussion (*M* = 8.49, *SD* = 6.19) as opposed to baseline (*M* = 2.33, *SD* = 2.95), a statistically significant mean increase of 6.16, 95% CI [5.00, 7.33], $t(103) = -10.48$, $p < .001$, $d = 1.03$. An additional paired-samples t-test was used to determine whether there was a statistically significant mean difference between athletes' severity scores at baseline and post-trauma following a suspected concussion. Twenty-six outliers were detected, as inspected on a boxplot, and subsequently removed from the data due to skewness and kurtosis. Following removal of outliers, the assumption of normality was not violated, as assessed by skewness and kurtosis values. As expected, athletes also reported increased severity of symptoms following a concussion (*M* = 9.38, *SD* = 8.22) compared to baseline (*M* = 3.23, *SD* = 4.97), a statistically significant mean increase of 6.15, 95% CI [4.59, 7.72], $t(77) = -7.83$, $p < .001$, $d = 0.89$.

Following demonstrated increases in symptoms and severity from baseline to post-trauma, an ANCOVA was utilized to control for individual baseline variance amongst athletes who sustained concussions and underwent post-trauma evaluations. Furthermore, the ANCOVA was calculated to determine whether athletes with a headache history (*n* = 10) reported more symptoms following a concussion compared to athletes without a headache history (*n* = 94), after controlling for their respective baseline symptoms. Post-trauma SCAT-5 total symptom scores were analyzed after controlling for individual baseline SCAT-5 total symptom scores. There were no outliers in this data, as assessed by no cases with standardized residuals greater than +/- 3 standard deviations. After adjustment for baseline SCAT-5 total symptom scores, there was no statistically significant difference in post-trauma SCAT-5 total symptom scores between athletes with and without a headache history, $F(1,101) = 0.775$, $p = .387$, partial η2 = .007. Post-hoc analysis was performed with a Bonferroni adjustment. SCAT-5 total symptom score from baseline to post-trauma was not statistically significantly greater in athletes with a headache history (*M* = 9.41, *SE* = 1.83) compared to athletes without a headache history (*M* = 11.20, *SE* = 0.90), a mean difference of -1.80, 95% CI [-5.86, 2.28], $p = .383$, failing to support hypothesis 2.1.

An additional ANCOVA was calculated to determine the effect of athletes with (n= 10) and without a headache history (n= 94) on post-trauma SCAT-5 Symptom Severity scores after controlling for individual baseline SCAT-5 Symptom Severity scores. There were no outliers in this data, as assessed by no cases with standardized residuals greater than +/- 3 standard deviations. After adjustment for baseline SCAT-5 Symptom Severity scores, there was no statistically significant difference in post-trauma SCAT-5 Symptom Severity scores between athletes with and without a headache history, $F(1,101) = 1.20$, $p = .276$, partial η2 = .012. Post-hoc analysis was performed with a

Bonferroni adjustment. SCAT-5 Symptom Severity score from baseline to post-trauma was not statistically significantly greater in athletes with a headache history (*M* = 12.05, *SE* = 1.83) compared to athletes without a headache history (*M* = 19.23, *SE* = 1.97), a mean difference of -7.18, 95% CI [-20.17, 5.81], *p* = .276, failing to support hypothesis 2.1. See Table 3 for a comparison of baseline and post-trauma total symptom and severity scores amongst athletes with and without a headache history.

Recovery Length History. Recovery length was coded based on approximate reported recovery length for athletes with previous suspected concussions. Refer to the data analysis section above for coding information. An independent samples t-test was calculated to determine whether there were differences in reported suspected concussion recovery length related to a prior concussion between athletes with a headache history (*n* = 45) and athletes with no headache history (*n* = 224). Prior suspected concussion recovery length for headache groups were normally distributed, as assessed by skewness and kurtosis values less than 2.0, and there was homogeneity of variances, as assessed by Levene's test for equality of variances (*p* = .137). Reported prior suspected concussion recovery length was not significantly longer for athletes with a headache history (*M* = 4.18, *SD* = 2.07) compared to athletes without a headache history (*M* = 3.65, *SD* = 2.76), failing to support hypothesis 3.1, *M* = -.526, 95% CI [-1.23, 0.18], *t*(267) = -1.46, *p* = .145.

Chapter 6: Discussion

As previously suggested, examining the degree to which pre-existing headaches impact student-athletes at baseline and complicate concussion severity and recovery is imperative not only for diagnosis, but also for determining what actions should be taken to aid in recovery (i.e., academic accommodations, referral to neurologist for co-management of headaches, etc.). Currently, the majority of headache and migraine research is medical in nature (e.g., developing a better understanding of pathophysiology), whereas substantially less research exists on the impact of headaches/migraines on cognition and SRC. In addition, as previously mentioned, existing research regarding the impact of headache or migraine on neuropsychological testing performance is rather inconsistent in its findings, suggesting a need for further research to clarify what impact pre-existing headache disorder may have on both baseline neurocognitive performance and after a suspected concussion. This study attempted to provide more data to tip the scales in one direction or the other.

Prior to interpreting SCAT-5 and ImPACT testing comparisons, the significant effect of demographic information including gender, age, education, and medication usage is addressed. A significant effect of gender on the history of headache and/or migraine group and no history of headache and/or migraine group was found. Although headaches and/or migraines are typically two-to-three times more prevalent in females than males, and three-to four-fold more prevalent in females following puberty compared to males (Al-Hassany et al., 2020), current test results suggest that headache and/or migraine is more commonly reported in males than females. There is a strong likelihood that this result relates to the particular sample of athletes surveyed rather than an increase in headache and/or migraine prevalence in males, since the sample consisted of 65.1% males and 34.9% females. Therefore, the significant effect of gender more than likely stems from the number of males vs. females that were sampled.

Additionally, a significant effect of age on the history of headache and/or migraine group and no history of headache and/or migraine group was found. Despite a *statistically* significant difference in age, the mean age of athletes in the headache and/or migraine group was 19.57 years, while the mean age of athletes in the non-headache and/or migraine group was 19.94 years. Although the difference in ages is statistically significant, the significance difference of 0.37 years lacks imperative clinical value in a sample of college students and therefore, age was not considered as a clinically significant value in examining the differences amongst athletes with and without a history of headache and/or migraine. Furthermore, a significant effect of education was found between the two headache history groups. However, clinical significance was not observed, such that the mean education of athletes in the headache and/or migraine group was 13.47 years, while the mean education of athletes in the non-headache and/or migraine group was 13.73 years. Thus, education was not considered as a clinically significant value in examining the differences amongst athletes with and without a history of headache and/or migraine.

Lastly, there was a significant effect of medication usage between the headache groups. Athletes with a history of headache and/or migraine were on average more likely to report medication usage compared to athletes without a history of headache and/or migraine. Although this difference was relatively small, it is more likely that athletes with a pre-existing condition of headache and/or migraine are taking medication compared to athletes with no history of headache and/or migraine, since the majority of the headache group reported receiving treatment for their condition. Although the possibility of medication usage impacting results is apparent, this factor could not be ruled out due the sheer number of athletes reporting taking medications in addition to a history of headache and/or migraine (*n* = 51). Additionally, athletes were not required to report their reasons for taking medication, such as taking medication specifically to control headache and/or migraine, so analyses specific to athletes taking headache medications were not conducted. Therefore, further research is necessary to determine the effects that medication usage may have on the following results.

Current results revealed significant differences in total reported symptoms and symptom severity between headache groups at baseline, in that athletes with a headache history reported more symptoms and higher symptom severity compared to athletes with no headache history. To ensure headache history was a significant factor between this finding, an additional test was conducted and resulted in headache-specific symptoms being significantly higher in the headache group compared to the non-headache group. This supports hypothesis 1.1 and suggests that athletes at baseline with a headache history are more likely to report typically experiencing symptoms, including headache symptoms, and have more severe symptomology. These findings also support utilizing individual baseline tests and symptom checklists for concussion protocols, rather than relying exclusively on group norming and symptom base rates, due to observed differences among typical symptom and symptom severity in athletes at baseline. Because this study did not obtain specific information related to frequency, severity, and treatment of headaches and/or migraines, further analyses could not be made. Moreover, since significant differences were discovered between the headache history and non-headache history groups, addition of a questionnaire or specific interview questions to gain a more well-rounded description of headache history may be warranted. Therefore, future research should aim to develop a better understanding of the specific relation between severity, frequency, and treatment of pre-existing headaches and/or migraines in comparison to baseline concussion testing performance amongst athletes with no headache or migraine history. Including background information regarding severity, frequency, and treatment of pre-existing headaches and/or migraines has potential to assist even further with differentiating pre-existing symptoms from post-concussive symptoms, an already vital factor in determining whether an athlete has sustained or recovered from a concussion.

Additionally, findings suggest that ImPACT visual memory performance at baseline is significantly lower for athletes with a history of headache and/or migraine compared to athletes without a history of headache and/or migraine. This finding alludes to the idea that a history of headache and/or migraine may relate to worse performance at baseline on visual memory tasks. However, performance on the SCAT-5 verbal memory tasks, including immediate and delayed recall of a word list, as well as ImPACT verbal memory performance were not significantly different at baseline for athletes with and without a history of headache and/or migraine. Subsequently, hypothesis 1.2 was partially supported. However, these contrasting results suggest a possible effect across ImPACT verbal and visual memory testing. For example, differences amongst memory performances may be influenced by types of migraines, as it has been shown that individuals who experience migraine with aura will perform worse on both verbal and visual memory tasks, whereas individuals with no aura may only demonstrate lower performance on visual-based memory tasks (Le Pira et al., 2000). Because the present study did not include a complete evaluation of pre-existing factors and characteristics related to their headache and/or migraine, it is possible many of the sampled athletes do not experience aura, leading to this discrepancy in performance on visual and verbal memory tasks. However, further research is warranted in determining the direct cause of these differences amongst athletes with and without histories of headache and/or migraine and should include specific factors such as presence of aura to perhaps better understand this apparent discrepancy in visual and verbal memory performance.

Current results also indicate significant differences in psychomotor speed, as assessed by ImPACT visual motor composite scores and reaction time composites at baseline, between athletes with and without histories of headache and/or migraine. Specifically, athletes with a history of headache and/or migraine performed worse than athletes without a history of headache and/or migraine on visual motor speed, thus, supporting hypothesis 1.3. In addition, athletes with a history of headache and/or migraine performed slower than athletes without a history of headache and/or migraine in the reaction time composite, also supporting hypothesis 1.3. This result suggests that athletes with a history of headache and/or migraine perform worse on visual processing, learning and memory, and visual-motor response speed. However, specific aspects of this composite score were not examined to determine if there are individual differences amongst each aspect of the score, so determination may not be made about which specific aspect(s) comprising the score were different. Additionally, athletes with a history of headache and/or migraine performed slower on the ImPACT reaction time composite compared to athletes with no history of headache and/or migraine, which supports previous research by Le Pira et al. (2000), Mulder et al. (1999), and Hooker and Raskin (1986). Nevertheless, these differences suggest an overarching disparity amongst the two groups and clinicians should consider this difference when collecting baseline data and utilizing individual baselines as a comparison factor following a suspected concussion. Additionally, after a suspected concussion, clinicians may need to take extra precautions when interpreting post-injury test results of individuals with a headache and/or migraine history, especially in situations where a baseline is not available. Because of these apparent differences in baseline performance, it is possible that relatively lower visual memory and speed scores following a concussive injury may not represent as much of a concussion-related decline as that observed among other athletes without a headache and/or migraine history.

Furthermore, results revealed significant differences between baseline and post-trauma symptom and symptom severity scores, suggesting that on average, athletes experience an increase in symptoms and symptom severity following a concussion. While this was expected, individuals with a history of headache and/or migraine did not demonstrate a substantially larger increase in symptoms and symptom severity from baseline to post-trauma after controlling for their baseline symptoms and symptom severity scores. Indeed, current data suggests that although the number and severity of symptoms significantly increase following a concussion, this increase does not become significantly greater for athletes reporting a history of headache and/or migraine compared to athletes with no history of headache and/or migraine when their baseline symptoms are considered. Thus, hypothesis 2.1 was not supported; however, this finding still appears to have clinically meaningful significance. Specifically, these findings once again highlight the importance of obtaining individual baselines, as clinicians evaluating athletes with a history of headache and/or migraine for a concussion who reported greater symptoms and severity at baseline can more easily take this into consideration when interpreting post-concussive symptom scores.

Lastly, in examining the reported recovery time of athletes following a previously suspected concussion, athletes with a history of headache and/or migraine self-reported experiencing significantly longer recovery times after a prior suspected concussion than athletes with no headache and/or migraine history. Although, this information was collected as self-report based on the athlete's most recent suspected concussion at baseline. Therefore, this information was not a concrete prospective measurement but rather an estimate on recovery time related to a prior injury. Additionally, the number of previous concussions and other confounding factors, such as other medical diagnoses, were not considered in the scope of this study. Nevertheless, it is possible that athletes may experience a longer recovery time following a concussion due to difficulty isolating pre-existing symptoms from lingering post-concussion symptoms, particularly since headache is the most often reported symptom of concussion. Additionally, the previously mentioned disparities amongst athletes' visual memory, visual motor speed, and reaction time scores with and without a headache history may result in a prolonged determination of recovery if cognitive scores continue to be relatively low after a concussion and proper comparison to one's own baseline is lacking. Despite athletes with a history of headache and/or migraine reporting on average a longer recovery time following a suspected concussion, this finding should be followed-up in future research and include other potentially contributing factors such as comorbidities, mechanism of injury, sport, and so on.

Limitations

Limitations of this study include the relatively small number of athletes with pre-existing headaches and/or migraines who also sustained a concussion during the course of this study, which limited comparisons of post-concussive symptom reporting. Due to this limited sample size, a prospective measure of length of concussion recovery was also not able to be sufficiently obtained. While the decision was made to utilize reported information regarding a prior suspected concussion instead, this information was based on self-report and was not corroborated, raising the possibility that reports of prior concussions and recovery times may have been inaccurate. Additionally, the overall lack of detail about athletes' background information pertaining to their reported headache disorders was limited. Headache history was obtained through self-report and no cross-checking was completed to ensure a diagnosis of a specific headache disorder was given by a medical provider. In addition, the only two headache disorders included in this study refer to the general terms of "headaches" and "migraines." Headache disorders were not broken into the classification units of primary or secondary, nor their respective subsets, so it is unknown the underlying cause or mechanism of headache in each athlete. Additionally, some athletes in the current study have experienced a history of headache or migraine but did not report being formally diagnosed by a medical doctor. These athletes were still used in the sample to obtain a suitable sample size and therefore all athletes that self-reported experiencing headaches, migraines, or having treatment for headaches or migraines were placed in the "history of headache and/or migraine" group. Furthermore, only a surface-level description of an athlete's headache disorder was obtained, and no headache-specific questionnaires were distributed to athletes. In the future, a questionnaire to determine additional characteristic such as the severity, frequency, and any other diagnostic considerations of the headache disorder may be useful for research purposes.

Chapter 7: Conclusion

This study provides evidence regarding the influence of pre-existing headaches and/or migraines on neurocognitive testing and symptom endorsement, specifically in a collegiate athlete population prior to and following a concussion. There appears to be clinical implications with future research narrowing the scope on specific headache and migraine factors on neurocognitive testing with the verbal and visual memory tasks, particularly the SCAT-5 and ImPACT. Although the literature is quite mixed, continued research on the relationship between pre-existing headache and/or migraine and neurocognitive performance may eventually tip the scales in one direction or another. Despite aspects of this study pointing toward the usage of individual baselines rather than collective group norming for comparisons following concussion, a normed baseline group specific to headache and/or migraine history should be considered when individual baseline testing may not be available. Additionally, this data indicates that there are discrepancies amongst athletes with and without a headache history in verbal memory, reaction time, and visual motor speed skills at baseline. These discrepancies are essential to understand when determining whether there is significant change in cognition following a suspected concussion and whether an athlete can return to play. Furthermore, due to specific differences in testing scores, separate recommendations should be made and tailored to individual athletes with a history of headache and/or migraine based on differences amongst symptoms, severity of symptoms, and neurocognitive testing (e.g., visual memory, reaction time, visual motor speed), albeit future research should examine which kind of recommendations should be made.

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Table 1.

Descriptive Statistics of Athlete Demographic Information

	Variable	*N*	Percent
Headache and/or Migraine Group			
	Gender		
	Female	68	47.2
	Male	76	52.8
	Race and Ethnicity		
	Asian	1	0.7
	Black/African American	22	15.3
	Hispanic/Latino	14	9.7
	Native Hawaiian/Other Pacific Islander	1	0.7
	White	94	65.3
	Two or More Races	12	8.3
	Age (years)		
	17	3	2.1
	18	50	34.7
	19	26	18.1
	20	25	17.4
	21	15	10.4
	22	18	12.5
	23	6	4.2
	24	1	0.7
	Education (years)		
	12	56	38.9
	13	25	17.4
	14	23	16.0
	15	23	16.0
	16	16	11.1
	19	1	0.7
Non-Headache and/or Migraine Group			
	Gender		
	Female	326	33.1
	Male	659	66.9
	Race and Ethnicity		
	American Indian/Alaska Native	4	0.4
	Asian	13	1.3
	Black/African American	137	13.9
	Hispanic/Latino	68	6.9
	Native Hawaiian/Other Pacific Islander	5	0.5
	White	692	70.3
	Two or More Races	66	6.7

Age (years)		
17	26	2.6
18	246	25.0
19	127	12.9
20	222	22.5
21	197	20.0
22	103	10.5
23	36	3.7
24	19	1.9
25	6	0.6
26	1	0.1
27	1	0.1
29	1	0.1
Education (years)		
12	301	30.6
13	113	11.5
14	231	23.5
15	240	24.4
16	96	9.7
18	2	0.2
19	2	0.2

Table 2.

Medians, Mean Ranks, and Mann-Whitney U Tests for Neuropsychological and Symptom Scores

Variable	Headache and/or Migraine Group		Non-Headache and/or Migraine Group		*U*	*z*
	Mdn	mean rank	*Mdn*	mean rank		
Baseline Symptom Score	0.00	708.52	3.00	458.97	82434.00**	9.83
Baseline Headache-Specific Score	1.00	762.22	0.00	536.17	99319.50**	10.80
Baseline Severity Score	4.50	768.45	1.00	535.26	100217.00**	8.30
ImPACT Verbal Memory Composite	91.00	534.97	91.00	569.39	66596.00	-1.19
ImPACT Visual Memory Composite	79.00	514.91	82.00	572.32	63707.50*	-1.97
SCAT-5 Immediate Memory	21.00	563.42	21.00	575.78	72472.00	0.43
SCAT-5 Delayed Memory	7.00	568.39	7.00	541.84	6785.50	-0.92
ImPACT Visual Motor Composite	79.00	494.34	82.00	575.33	60745.50**	-2.78
ImPACT Reaction Time Composite	0.59	615.59	0.57	557.60	78205.00*	2.00

Note. *p < .05, **p < .01

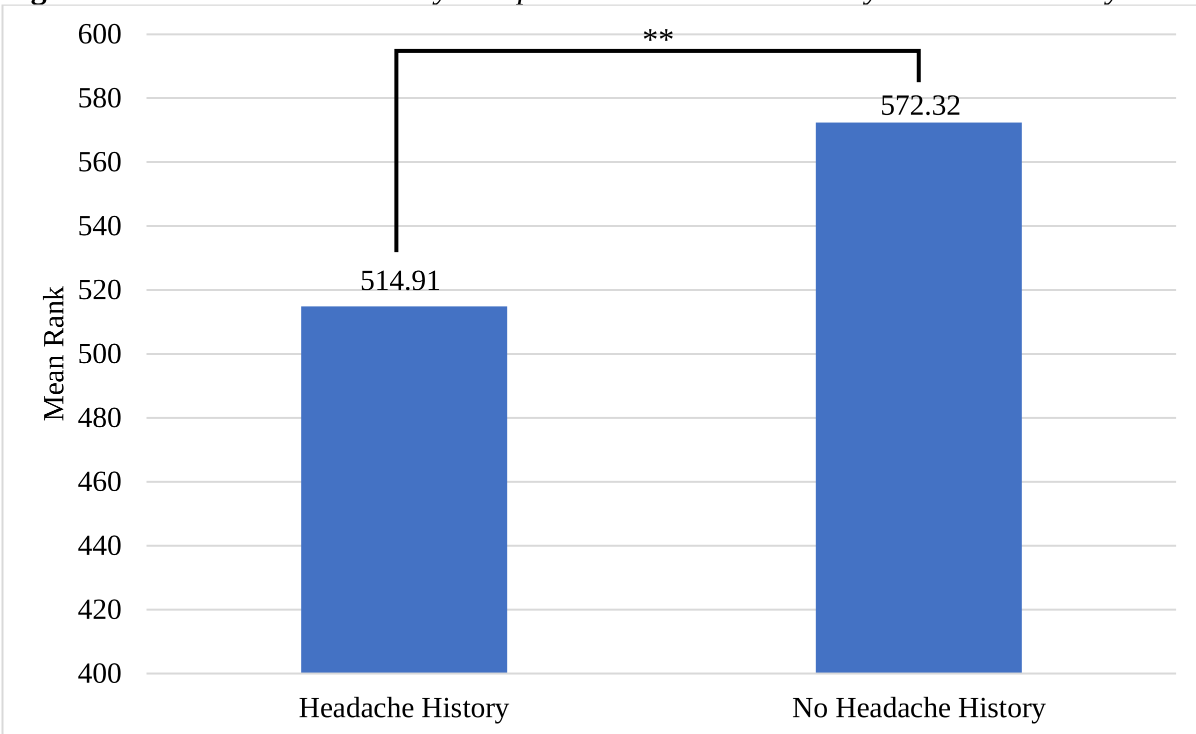
Table 3.

Means, Standard Errors, and ANCOVA Tests for Change Across Baseline to Post-Trauma

Variable	Headache and/or Migraine Group		Non-Headache and/or Migraine Group		*F*	η2
	M	*SE*	*M*	*SE*		
Total Symptom Score	9.41	1.83	11.20	0.90	0.775	.007
Symptom Severity Score	12.05	1.83	19.23	1.97	1.20	.012

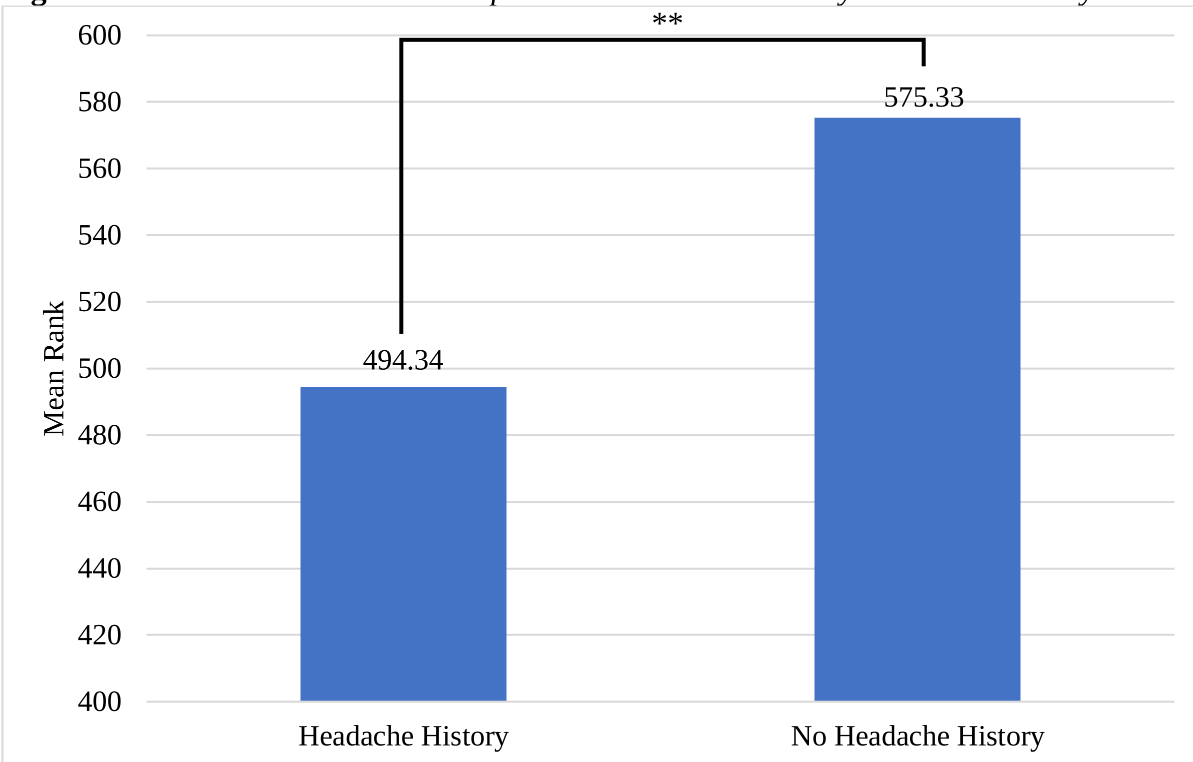
Note. *$p < .05$, **$p < .01$

Figure 1. *ImPACT Visual Memory Composite Mean Rank Scores by Headache History*



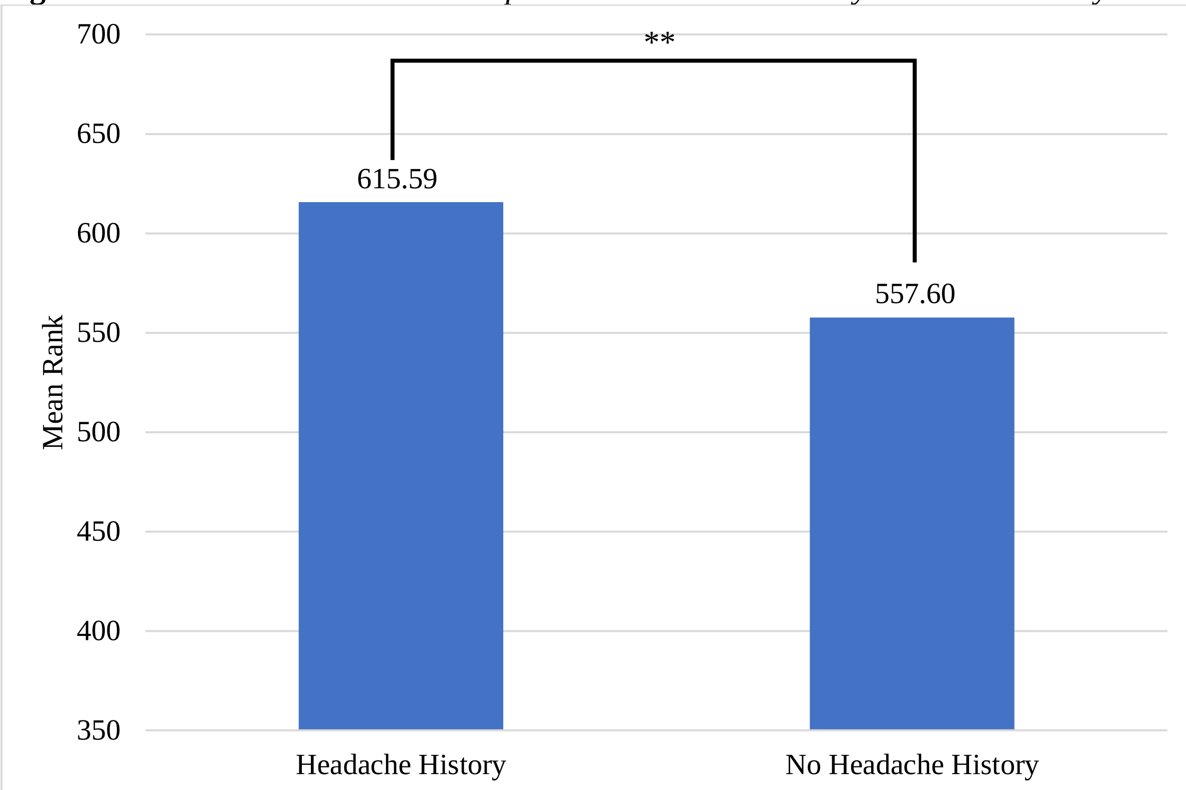
Note. $^{**}p < .05$

Figure 2. *ImPACT Visual Motor Composite Mean Rank Scores by Headache History*



Note. ***p* < .05

Figure 3. *ImPACT Reaction Time Composite Mean Rank Scores by Headache History*



Note. **p < .05