Neurocognitive, Postural Stability, and Health-Related Quality of Life Deficits in Secondary School Athletes Without a Clinically Diagnosed Sport-Related Concussion

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Abstract

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Neurocognitive, Postural Stability, and Health-Related Quality of Life Deficits in Secondary School Athletes Without a Clinically Diagnosed Sport-Related Concussion

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Introduction: It has been determined that 67,000 high school athletes per year are clinically diagnosed with a sport-related concussion (SRC); however, many SRCs go undiagnosed. The risk of the undiagnosed SRCs does not go without concern. ***Objective:*** The purpose of this study was to determine if neurocognitive, postural stability, and health-related quality of life (HRQOL) changes occur in athletes during the duration of a high school football season. ***Methods:*** Participants completed a history/demographic questionnaire, Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), SWAY Balance Mobile application (SWAY), and HRQOL surveys: Short Form Health Survey (SF-12) and Pediatric Quality of Life Inventory (PedsQL) at three time points (pre-, mid-, and postseason). ***Main Outcome Measures:*** Scores on the ImPACT, SWAY, and HRQOL surveys. ***Results:*** Balance, mental HRQoL, and reaction time improved over the course of the season. However, physical HRQoL, verbal memory, and impulse control decreased over the course of the season. ***Conclusion:*** Physical HRQOL, verbal memory, and impulse control decreased over the season, indicating that these areas may be affected by competing in a collision sport.

Preface

Chapter 3 contained within the thesis document serves as a prepublication manuscript. This manuscript has been formatted to meet the guidelines set forth by the *Journal of Athletic Training* and Thesis and Dissertation Services at Ohio University. The heading style and reference citation style follow the guidelines of the AMA Manual of Style (10th ed., 2007).

Dedication

I dedicate this research thesis to my wonderful parents who have helped me through this process as so many others with love and support. My parents always have supported me in my goals and dreams and helping me in any way they can to achieve them.

Mom and Dad, You have given me the opportunity to excel and accomplish so much in my life. I could not have done any of it without your love and support. I could never thank you enough. I love you both.

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Chapter 1: Introduction

Sport-related concussion (SRC) is a topic that has acquired increasing attention over the last 10 years in sports medicine. A PubMed search yielded a total of 571+ articles published in relation to SRC. In 2009 a total of 89 articles were found; in 2009-2016, an additional 367 articles; and in 2017, an additional 115+. SRCs can occur during any sports-related activity; however, the rates of concussions in contact and collision sports are higher than the incidence of other recorded injuries.[1,2] The increase in concussion rates is a reasonable concern, with approximately 300,000 SRCs occurring each year.[3] The sport that receives the greatest concern regarding the effects of SRCs is football. SRCs have been linked to the relevant style of play, high rate of impacts, and extent of participation.[4] In recent studies of high school football players, approximately 67,000 players per year are clinically diagnosed with a SRC, which accounts for about 60% of recorded concussions.[3,5] Of greater concern is the fact that a similar number of concussed athletes go undiagnosed. This is significant because undiagnosed SRCs may result in severe behaviors, signs and symptoms, mental health disorders, or possibly death.[5] Taking this into consideration, it is important that clinicians understand what is affecting athletes during a SRC. The subjective nature of cognitive and balance testing makes it difficult to detect SRCs.[6] Neurocognitive and balance deficits are not always affected to the same degree. SRCs are a challenge for clinicians to diagnose because each SRC is unique, meaning that no two SRCs will present identically.[7,8]

Neuropsychological testing has gradually become the expected practice for the management and diagnosis of a SRC.[5] There has yet to be established a “gold standard” protocol. This making the evaluation of a SRC particularly difficult due to the lack of availability of a definitive diagnostic tool. Experts have advocated a multifaceted approach, because studies show that SRC affects multiple areas, including self–reported symptoms, postural control, and neurocognitive function.[8] Furthermore, the literature has increasingly emphasized the need for objective SRC assessments and using objective preparticipation baseline tests for postinjury comparison.[9] Establishing a baseline is important for determining clinically significant changes in brain function after sustaining a SRC.[10]

One element of the SRC assessment battery that is considered to be the most important is neurocognitive assessment, because it provides the most pertinent information during the clinical evaluation process.[11] Computerized neurocognitive assessments are becoming the preferred means of testing neurocognitive deficits; often they are based on the traditional neuropsychological tests, which measure verbal memory, visual design memory, concentration, visual processing speed, and reaction time. [9] Neuropsychological tests are used in neurological populations with focal and diffuse lesions.[10] Application of neuropsychological batteries in psychiatric research and practice is limited, but in recent years has become incorporated into efforts to understand involvement of neural systems in pathophysiology of such major disorders such as schizophrenia.[11] Computerized neurocognitive scanning is beginning to become recognized in determining cognitive deficits in schizophrenics.[12]

Postural stability testing has been viewed as an adjunct to SRC assessment testing. Clinicians are starting to recognize the importance of the effects of motor function on the injured brain.[8] Postural stability has been defined as the ability to maintain control over one's center of gravity or equilibrium within the limits of stability, over a base of support.[13] The areas of the brain that are disrupted as a result of a SRC are responsible for the maintenance of equilibrium.[13] This is maintained primarily through three different sensory inputs: vision, somatosensory input, and vestibular input.[5] Studies have confirmed the increase of postural sway in the evaluation of acute mild head injuries.[1,14] Testing for simple motor function, in the case of reaction time, have been seen to take longer to return to baseline following a SRC than that of cognitive function.[15] There are many ways to test postural stability when a SRC is suspected. The most well known is the Rhomberg test, a diagnostic tool in the classical neuromotor balance screen. There are more quantitative and objective assessment tools that are replacing the Rhomberg.[1,7] Other common postural stability tools are the Sport Concussion Assessment Tool (SCAT), the Balance Error Scoring System (BESS), and the Sensory Organization Test (SOT). Technology has allowed for the development of better clinical diagnostic tools that are quick and easily administered on the field using smartphone balance applications. The use of smartphones in the tracking and monitoring of wide range of conditions has continued to grow in numerous patient populations including dementia, Alzheimer disease, activity levels of cardiac and stroke rehabilitation, as well as in home care monitoring of sleep apnea, diabetes, and mental head disorders.[16] There have been few studies about using applications of smartphones for the assessment of postural stability.[13,17–19] Nevertheless, smartphone applications could be beneficial, cost efficient, and readily available sideline tools for the assessment of postural stability in the athletic setting.[28,29]

Heath-Related Quality of Life (HRQOL) outcome measures have been a critical component in patient care for a variety of injuries, disorders, and illnesses. The concept corroborates a person's sense of well-being and satisfaction with their life in terms of physical, psychological, and social functioning, perceptions of self-efficacy; independence; social support; and self-concept.[20] The ability to understand patients' views about how they are functioning in all aspects of everyday life is an important component to the success of their recovery. It is important to be able to measure the perception of health of the population to assess the benefit of health care interventions and target services.[21] Unfortunately, it has been shown that existing measures are too narrow, particularly in general practice, to measure the benefit of a wide range of parameters including mobility, functioning, mental health, and over all well-being.[21] Studies have shown that those with SRC have a lower HRQOL.[20,22] Without a true scale for the SRC in HRQOL it is important that other studies are conducted to validate the use of these scales in those with SRCs.[22]

There is vast literature on the effects of concussions on athletes, but few studies examine what athletes at high risk for head acceleration injuries experience. This study will allow for the understanding of what changes are occurring in the brain of athletes during a single collision sport season. Sport medicine specialists needs to know what is affecting the brain function in the unimpaired brain when there is a high risk of impact. This will allow for a better understanding of what is affecting brain impairment when a SRC is clinically diagnosed. The purpose of this study was to determine if neurocognitive, postural stability, and health-related quality of life (HRQOL) changes occurred in nonconcussed athletes during the duration of a football season in a secondary school.

RESEARCH QUESTIONS AND HYPOTHESES

1. Does participating on a high school football team affect neurocognition as measured by the ImPACT test over the course of a single season?
   a. There will be neurocognitive deficits, shown on ImPACT test measures in high school football players between initial pre- to midseason testing.
   b. There will be neurocognitive deficits, shown on ImPACT test measures in high school football players between the initial pre- to postseason testing.
   c. There will be neurocognitive deficits, shown on ImPACT test measures in high school football player between mid- and postseason testing.
2. Does participating on a high school football team affect postural stability as measured through the use of SWAY Balance over the course of a single season?
   a. There will be postural stability deficits shown using measures from the SWAY Balance application in high school football players between initial pre- to midseason testing.
   b. There will be postural stability deficits shown using measures from the SWAY Balance application in high school football players between initial pre- to postseason testing.
   c. There will be postural stability deficits shown using measures from the SWAY Balance Mobile application in high school football players between mid- and postseason testing.
3. Does participating on a high school football team affect HRQOL as measured by the SF-12 and PedsQL over the course of a single season?

a. There will be HRQOL changes shown using measures from the SF-12 and PedsQL in high school football players between initial pre- to midseason testing.

b. There will be HRQOL changes shown using measures from the SF-12 and PedsQL in high school football players between initial pre- to postseason testing.

c. There will be HRQOL changes shown using measures from the SF-12 and PedsQL in high school football players between mid- and postseason testing.

INDEPENDENT VARIABLES

1. Time
   a. Pre-season (August 1, 2016).
   b. Mid-season (October 1, 2016).
   c. Post-season (October 29, 2016).

DEPENDENT VARIABLES

1. Neurocognition
   a. ImPACT: Includes 5 Composite scores and a Total Symptom Composite score.
      - Composite 1: Verbal Memory Composite.
      - Composite 2: Visual Memory Composite.
      - Composite 3: Processing Speed Composite.
      - Composite 4: Reaction Time Composite.
      - Composite 5: Impulse Control Composite.

- Total Symptom Composite.

2. Postural Stability

   a. SWAY Mobile Balance Application: Overall score of postural sway.

3. Health Related Quality of Life

   a. SF-12: Contains 2 summary scores.

      - PCS: Physical Component Summary Score.
      - MCS: Mental Health Component Summary Score.

   b. PedsQL: Multidimensional child self-report, consisting of 23 items broken into 4 domains.

      - Physical Functioning.
      - Social Functioning.
      - Emotional Functioning.
      - School Functioning.

ASSUMPTIONS

1. The administration of testing at pre-, mid-, and postseason points were done without variation for each participant.
2. Participants completed ImPACT testing honestly and to the best of their ability.
3. Participants completed the SWAY Balance testing to the best of their ability.
4. Participants answered all HRQOL questionnaires honestly and to the best of their ability.

5. Evaluation of the data for neurocognition, postural stability, and HRQOL measures was consistent for each participant.

LIMITATIONS

1. Participants were all males
2. Participants were all members of the Marietta High School football team who had not sustained a SRC in the last 6 months.
3. Small sample size.

DELIMITATIONS

1. Participants were limited to those that played football at Marietta High School.
2. Participants were all healthy and physically active members of the Marietta High School football team.
3. Measurements were obtained during three testing sessions (pre-, mid-, and postseason).
4. The evaluator of (ImPACT or SWAY Balance) testing for this study was also the main researcher and therefore could be biased due to not being blinded.

Chapter 2: Literature Review

INTRODUCTION

The concern about SRCs in the world of athletics has grown tremendously in the past years. This has made it important for the healthcare professionals who deal with diagnosis and management of sports-related SRCs to be sure that the correct decisions are being before athletes for return to play. It has been shown that no two SRCs are alike, and the effects of neurocognitive and balance deficits are not always affected to the same degree.[6] Neuropsychological testing has become the standard way to diagnose and manage SRCs.[23] Worldwide, it has been recognized as the most sensitive and sophisticated means for detecting and characterizing neurocognitive deficits resulting from central nervous system trauma.[8] There is still no "gold standard" for the diagnosis of SRCs; therefore, it is important that clinicians use all the tools and resources available for the diagnosis and management of SRCs. Furthermore, the literature has emphasized the need to increase the objectivity of SRC assessment using objective preparticipation baseline assessments as a basis for postinjury comparison.[24]

Computerized neurocognitive assessments are becoming the preferred means of testing neurocognitive deficits often to measure verbal memory, visual design memory, concentration, visual processing speed, and reaction time.[24] Neuropsychological testing has been used often in neurological populations with focal and diffuse lesions. [9] Application of neuropsychological batteries in psychiatric research and practice has been used for over 50 years to understand involvement of neural systems in pathophysiology of major psychiatric disorders.[10] Computerized neurocognitive scanning is being used to determine cognitive deficits in individuals with psychiatric disorders.[11] Postural stability testing is being used as an adjunct to SRC assessment testing. Clinicians are starting to recognize the importance of the effects of motor function on the injured brain.[23] Postural stability is defined as the ability to maintain control of one's center of gravity or equilibrium within the limits of stability, over a base of support.[13] Postural stability is maintained primarily through three different sensory inputs: vision, somatosensory input, and vestibular input.[5]

Throughout this review of current literature regarding the effects of SRCs, criteria for diagnosis of SRCs, undiagnosed SRCs, and subconcussive blows will be discussed. Also, neurocognitive deficits, postural stability, and health-related quality of life outcome measures along with each of the diagnostic tools that fall under these categories will be reviewed.

EFFECTS OF SPORT-RELATED CONCUSSION

SRCs occur when linear and/ or rotational forces are transmitted to the brain; this results in shear strain of the underlying neural elements.[25,26] SRCs result in a multitude of physical, emotional, and sleep-related symptoms.[7] SRCs involve complex pathophysiological processes that affect the brain, which are caused by biomechanical forces. A direct blow to the head is not required for the development of a SRC.[25] There are many inclusion factors for SRCs: (1) a direct blow to the head, face, neck, or other area of the body that causes an impulsive force that is transmitted to the head; (2) rapid onset of short-lived impairments of neurometabolic dysfunctions that resolve spontaneously; (3) neuropathological changes, although the acute clinical symptoms mainly reflect a functional disturbance rather than a structural injury; (4) clinical symptoms that are graded and may or may not involve loss of consciousness.[25] The resolution of SRC symptoms typically demonstrates a sequential course.[25] Additionally, SRCs are typically associated with grossly normal structural neuroimaging studies.[25]

DIAGNOSING SPORT-RELATED CONCUSSION CRITERIA

SRCs are considered to be one of the most difficult sports-related injuries to diagnose. SRCs are transient and thus include a wide range of clinical signs and symptoms consisting of somatic, cognitive, and sensorimotor indicators.[27,28] Suggested criteria are any observable alterations in mental status or consciousness following a blow to the head or body; the presence of loss of consciousness and/or anterograde or retrograde amnesia; or, self-reported symptoms including headache, nausea, dizziness, balance or visual problems.[5,14,28] Therefore, clinicians must be skilled in the evaluation of head injuries.

Many states in the United States have legislated return-to-play (RTP) status requirements for athletes who have sustained a SRC.[26] The states require the education of athletes, parents or guardians, and coaches; removal from play or practice at the time of the suspected SRC; and, written clearance for RTP or practice by a licensed healthcare provider.[26] This has led to the development of neuropsychological testing for the management of SRCs. During the evaluation of sports-related SRCs, it is important that the clinician use a multifactorial approach to help assist in the diagnosis and management of SRCs, including self-reported signs and symptoms, postural control, and neurocognitive function. Originally, diagnostic criteria for a SRC were dependent on any loss of consciousness (LOC). Subsequently, has been shown that SRCs and associated LOC is found in a minority of patient (10%), whereas more commonly associated symptoms are confusion, amnesia, dizziness, visual disturbances, and headaches.[3,26]

Postural control is another area that is examined during the diagnosis and management of a SRC. Under normal circumstances, an individual balances by integrating sensory information from visual, vestibular, and somatosensory systems. This information is then used for the proper selection of motor responses for the maintenance of postural equilibrium.[12] Balance tests (ie, BESS, SEBT) have been developed to determine sensorimotor deficits following a SRC.[27]

Neurocognitive function is the third area that is analyzed during diagnosis and management of SRCs. The neurocognitive assessment has been suggested to be the most important element of the SRC assessment battery, providing the greatest amount of information to the clinician during the evaluation process.[11] Multiple diagnostic tools have been developed for the assessment of neurocognitive deficits (ie, ImPACT, SCAT3). A test battery has been reported to be 23% sensitive to SRC when administered 2 days following an injury includes: the Hopkins Verbal Learning Test, Trail Making Test Part B, the Symbol Digit Modalities, the Stroop Color Word Test, and the Controlled Oral Word Association Test.[11]

UNDIAGNOSED SPORT-RELATED CONCUSSIONS

With the increasing number of diagnosed SRCs annually, there is an approximately equal number of SRCs that go undiagnosed.[4] Multiple factors contribute to the increase of undiagnosed SRCs. The major component is the reliance on subjective measures from the athlete. This complicates the diagnosis of SRCs because athletes tend to underreport or mask symptoms in anticipation of a more rapid RTP.[29] Other studies have shown that more than one third of athletes do not recognize their symptoms as a result of a SRC.[25] Athletes also tend to believe that their symptoms are not serious enough to warrant reporting.[25] Diagnosing SRCs is further complicated by the fact that signs and symptoms may not be present for several hours or days following the initial episode.[8] SRCs that go undiagnosed pose increased risks for catastrophic injuries. These potential consequences arise when an athlete has returned to play to early following a SRC and then experiences a condition known as second impact syndrome. Second impact syndrome occurs when an athlete has sustained a SRC from which they are still symptomatic and receive a second injury to the head.[25] The second injury could also be a minor blow to the chest or trunk. The end result of second impact syndrome, if not death, is severe mental impairment.[25]

SUBCONCUSSIVE BLOW

More recently, researchers have explored the effects on athletes who sustain multiple subconcussive blows during contact or collision sports that do not result in SRC-like symptoms. The long-term effects of neurocognitive complications following participation in contact sports remains unclear; however, neurological deterioration has been reported after concussive and multiple subconcussive blows.[30] Sub-SRC is defined as cranial impact that does not result in known or diagnosed SRC.[3] Since subconcussive blows do not result in acute clinical symptoms, it is difficult to study and research their effects.[30] Talavage et al[30] demonstrated that high school football players can exhibit measurable changes in neurocognitive performance and neurophysiology. Breedlove et al[30] noted correlations between measured changes and increased number of subconcussive blows that where sustained throughout a season. Modern-day athletics athletes are now bigger, stronger and faster. Their increased mass increases the kinetic energy introduced to blows to the head. Athletes becoming faster increases the velocity of impact and is the single greatest factor in the rise of concussive incidents.[3]

In one study, it was noted that there were measurable changes in brain physiology or neurocognitive function in participants, yet none of the individuals had symptoms that would have prompted a clinician to remove them from participation.[30] This shows that the athletes who are not clinically diagnosed with a SRC could be having neurocognitive or balance deficits during the duration of a sports season.

The effects of multiple subconcussive blows has the potential to contribute to the development of subacute and chronic sequelae such as depression, postconcussive syndrome, posttraumatic stress disorder, mild cognitive impairment, chronic traumatic encephalopathy, and dementia pugilsticia.[3] There is still a lack of evidence regarding subconcussive blows and the number of subconcussive impacts an athlete can sustain prior to ending their career.[3,30] This topic is still developing and evolving with the increased risk of exposures. Until short and long-term effects of multiple subconcussive blows are determined with increased evidence, it is suggested to limit the number of exposures to reoccurring cranial impacts during practice.

NEUROCOGNITIVE DEFICITS

Neurocognitive effects in contact sports have become a concern to sports medical personnel.[31] American football is one of the sports most likely to be affected.[31] But, the exact cause of neurocognitive complications following participation in contact sports is still unclear; they are probably linked to a combination of concussive and multiple subconcussive impacts.[30] In the clinical setting, the use of neuropsychological testing has now been widely recognized as both a sensitive and sophisticated way for detecting and characterizing neurocognitive deficits caused by central nervous system trauma or disease.[23] It has been suggested that neurocognitive testing is the most important element of the SRC-assessment battery because it provides the greatest amount of information during a clinical exam.[11,32]Many elements of cognitive function are potentially affected after a SRC, such as attention, processing speed, and working memory.[23]

Neurocognitive testing is used for many conditions in addition to SRC-related injuries. Neuropsychological testing is relevant to psychiatric diagnosis and treatment, a focal point of recent investigations.[9] The integration of assessment tools for cognitive deficits has taken place in neurological research and practice, eg, Alzheimer's research and toxin exposure.[9] Most recently, efforts have gone into understanding the neuropathophysiology of major disorders such as schizophrenia.[9] All of these disorders affect the same neurocognitive domains: abstraction and mental flexibility, attention, memory, and language.[10]

The detection of neurocognitive deficits in athletes is challenging because of the subjective nature of current tests.[30] These tests rely heavily on athlete perception of signs and symptoms. A lack of a definitive diagnostic tool for the evaluation of SRCs is lacking.[11] Nevertheless, multiple post-SRC assessments allow for the tracking of neurocognitive decrements and the subsequent recovery from SRCs.[32] Test batteries that included the Hopkins Verbal Learning Test, Trail Making Test Part B, the Symbol Digit Modalities Test, the Stroop Color Word Test, and the Controlled Oral Word Association Test have been reported to be 23% sensitive to SRCs when administered 2 days following injury.[11] Talavage et al[30] demonstrated that asymptomatic, nonconcussed high school football players could exhibit measureable changes in neurocognitive performance throughout the course of a season. Though pencil-and-paper assessments for neurocognitive deficits have been most common in the past, new advances in technology have shown computerized neurocognitive assessments to be beneficial.[11,33]

Immediate Post-Concussion Assessment and Cognitive Testing

Computerized neurocognitive testing has become widely recognized and used as an objective method for identifying subtle cognitive deficits in postconcussed athletes.[33] Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is designed for tracking recovery of days to weeks after a SRC.[31] ImPACT consists of three main parts: demographic data, neuropsychological tests, and Post-Concussion Symptom Scale (PCSCL).[34] Further the neuropsychological tests are broken down into 6 tests, each used to asses attention, memory, processing speed, and reaction time.[34] The PCSCL incorporated into ImPACT is a 21-symptom checklist that asks the athlete to rate each symptom on a 7-point Likert scale. This has been shown to be useful because the test uses “common” terms to describe the symptoms rather than medical terminology that athletes may not be able to interpret following an injury.[34] ImPACT also allows for the option of readministrating the PCSCL to see if the test itself has affected their symptoms. Raymond et al[35] reported base-rate of postconcussion symptoms in individuals without head injuries. The study determined that a mean average score of symptoms experienced was 9.49.[35]

Taking preseason baseline assessments has become the ideal before the start of an athletic sport season.[24,32] These are used for the comparison after a SRC to determine the presences of clinically significant changes in brain function.[24] The use of an athlete’s own baseline has been shown to be more accurate then matching them with age and sport normative data.[31] Among other benefits, computerized neurocognitive testing offers an advantage over standardized test administration and scoring due to improved measurement precision.[32] ImPACT has been validated by many studies to be an effective tool for SRC management, and does not show large practice effects sometimes seen in pencil-paper counterparts.[11,32,34,36] Lovell et al[37] followed concussed athletes 1 week postinjury, and compared them to age-matched control participants. It was found that the control group scores during ImPACT did not increase with multiple testing opportunities, supporting the conclusion that ImPACT is not hindered by a practice effect.[34] Maerlender et al[38] used ImPACT with healthy individuals and found that the Memory Composite scores (Verbal and Visual) had an increase in scores in each of the four testing points. For both the Verbal Memory and Visual Memory Composite scores, a higher score indicates a better score.[39] Though the study done by Maerlender et al[38] did not find any change between testing points in reaction time, a study by Del Rossi et al[40] found that when testing individual reaction times there was a decrease in time implicating that participants improved each time. Another study by Iverson et al[37] found that concussed high school athletes had decreased scores on the Verbal Memory Composite score. ImPACT has been validated by many studies, with 89.4% specificity and 81.9% sensitivity.[11,32,34,36] Likewise, the reliability if ImPACT has been reported to range from 0.54 to 0.76.[11]

The Sport Concussion Assessment Tool (SCAT)

The SCAT has been in use for many years for the sideline assessment of SRCs.[26] SCAT has eight components that include: SAC, modified BESS, Glasgow coma scale, physical sign score, Maddock's score, and coordination exam.[8,26] This tool has been designed to be used serially after a SRC and includes a "score card" that is used to track performance for each component over a period of time during recovery.[8] Due to the modifications of the original SCAT, it is likely to go from being used as a regular sideline tool to more of a " training room assessment tool" because of the increase in time needed to complete the testing.[8] Some of the components that make up the SCAT, SCAT2, or SCAT3 have been shown to have intra- and interrater reliability; the intraclass correlation coefficient (ICC) was demonstrated to have a higher intrarater reliability for the finger to nose and tandem gait tests than for the single leg stance.[8] Therefore, it has been recommended to eliminate the single leg postural stability tests because of the poor reliability.[8] The BESS was the other component to demonstrate both intra- and interrater reliability with ICC scores of 7.3 (intrarater) and 9.4 (interrater) calculated for the total BESS score.[8]

Standardized Assessment of Concussion (SAC)

SAC is commonly used as a sideline assessment tool that is useful, quick (approximately 5 minutes), and inexpensive.[26,31] It has been shown to be valid and reliable with little ceiling effect.[31] One of the downsides to the SAC is that, although it is shown to be sensitive initially after injury, it becomes less sensitive over subsequent days, weeks, and months.[31] Immediately after injury, SAC had 80% sensitivity with a decrease to 31% when assessment was administered at day 1 postinjury.[11] SAC assesses four domains of cognition: orientation, immediate memory, concentration, and delayed recall.[23] The test has a total composite score of 30 representing the overall index of cognitive impairment. A score of 26 or less is representative of sustaining a SRC. The test contains a neurologic screening and documentation of injury-related factors.[23]

POSTURAL STABILITY

Postural stability has been defined as the ability to maintain control of one's center of gravity or to maintain equilibrium within the limits of stability, over a base of support.[29] Stability is maintained primarily through three different sensory inputs: vision, somatosensory, and vestibular.[1,6,30] The feedback that is obtained through these systems sends commands to the muscles of each extremity, which then generates the appropriate contraction to maintain postural stability.[1] Under normal conditions, the visual and somatosensory information is adequate for the maintenance of postural stability. When there are known vestibular deficits, the use of senses within the inner ear are essential for balance when visual and somatosensory inputs are disrupted.[1,5] There are many known pathologic conditions that have been identified with postural instability such as moderate-severe traumatic brain injury, hemiplegia and craniocerebral injury, cerebellar atrophy and ataxia, and whiplash.[5] Loss of communication among the three sensory systems causes moderate-severe postural instability.[5] Most of these cases have associated symptoms such as dizziness, vertigo, tinnitus, lightheadedness, blurred vision, or photophobia.[1,5]

Along with the assessment of neurocognitive impairments, clinicians must be aware of the effects on motor control (ie, postural stability) and the components that are responsible for the maintenance of postural stability.[1] Many assessment tools have been developed to detect postural stability in athletes after sustaining a SRC. However, it is unknown which clinical test is best for detection of motor function deficits. Studies have confirmed there is an increase of postural sway in the evaluation of acute mild head injuries.[1,14] Following a SRC simple motor function (reaction time) takes a longer time to return to baseline levels (up to 14 days postconcussion) than cognitive function.[15] A decrease in postural stability (standing on a foam or tilting surface) measured 3 days following a SRC has been documented in the literature when compared to a control group.[12] Of more concern, is when an individual experiences multiple SRCs or subconcussive type impacts which may cause impairments for longer than 14 days postconcussion.[15] Another study showed that total sway did not differ from either a SRC group or healthy group, therefore, indicating that head-injured athletes do not sway more, but maintain their center of pressure (COP) at a greater distance from the center of their base of support and make fewer postural corrections.[6] Postural stability is examined in many other injuries and disorders, eg, anterior cruciate ligament reconstruction, neuropathy in diabetics, Familial dysautonomia and chronic ankle instability.[2,41] A study done on individuals with diabetic peripheral neuropathy demonstrated that these individuals can significantly improve their postural balance with diabetic-specific, tailored, sensory-based exercise training.[41]

The Rhomberg Test

Traditionally, clinicians have used the Rhomberg test for assessing postural instability for head-injured athletes.[7] The Rhomberg test is performed for 30-second intervals with the body positioned feet together and arms at side typically done for 3 trials.[6] But, in most recent years there has been a greater emphasis on quantitative and objective assessment tools to measure postural control.[1,7] Even though the Rhomberg test has been utilized to assess disequilibrium in athletes with SRCs, the advancement in technology has allowed for the use of computerized posturography as a more objective assessment.[42]

Balance Error Scoring System (BESS)

BESS is a valid, objective, time efficient, and inexpensive means for measuring postural stability, which frequently shows deficits in the first 48 to 72 hours after a SRC.[43] The BESS is a clinical assessment that was developed to assess postural stability on stable and unstable surfaces in 3 different stance positions. Each position is held for 20 seconds on both surfaces, while the evaluator counts the number of errors the athlete sustains (each time the athlete deviates from the original position).[36] Each condition can have a maximum number of 10 errors, with a total maximum composite score of 60.[36] A change of 3 or greater from an athlete's baseline is to be considered a minimal detectable change and the athlete is considered to have balance changes.[36] Although, a widely recognized clinical test, the BESS has been shown to demonstrate issues with intra- and interrater reliability with coefficients ranging from 0.78 to 0.96.[14,27,36] The sensitivity of the BESS is 0.34, and specificity ranges from 0.91 to 0.96 across 1-7 days postinjury.[26] Fox et al[8] examined a study on the effects of exercise and BESS performance of 36 NCAA Division I athletes. Athletes with a worse (higher) overall BESS score at 3 to 8 minutes after exercise returned to baseline BESS scores within 13 minutes. A vast amount of literature exists to support the use of the BESS as a sideline tool in the management and diagnosis of SRCs, however, the issues of reliability remain a concern.[8] Valovich et al[44] looked at a practice group and nonpractice group to determine if there was a practice effect with the BESS. They found that after administration of the BESS within the practice group there were significantly fewer errors on days 5 to 7 when compared to baseline.[44] This indicates that the BESS could be susceptible to a practice effect when administered at multiple points. Other studies have shown that postural stability measures have elicited a practice effect when administered multiple times.[7,38,40,44,45]

The Sensory Organization Test (SOT)

The SOT is administered on the NeuroCom Smart Balance Master System. This is a force-plate system that measures vertical ground reaction forces produced by the body's center of gravity moving around a fixed base of support.[7] The SOT exhibits disruptions in the visual and somatosensory information while measuring the ability to minimize postural sway.[7] The protocol for the test is 20 second trials under 3 different visual conditions (eyes open, eyes closed, sway referenced) with two different surface conditions (fixed, sway referenced).[1]

The SOT is considered to be a sophisticated means of assessing postural stability, but, is an expensive and not readily available tool in an athletic setting. Studies have reported that balance deficits persists up to 3 days following injury when compared with a controlled group, and was most evident when an athlete was standing on a foam or tilting surface.[5] Guskiewicz et al[42] found that overall postural stability deficits indicated problems during the first few days post injury, until approximately day 3. They found no significance after days 3-5 in those with acute SRC.[42] Particularly the SOT has been considered to be the "gold standard" for the assessment of postural stability and has high reliability among normal individuals, those with vestibular pathology, and those suspected of exaggerating symptoms.[14]

Smartphone Balance Applications

Technology has contributed to advancements in evaluating postural stability.[16] Smartphones, tablets, and multimedia devices have incorporated various sensors.

Specifically, sensors have included accelerometers, global positioning systems, gyroscopes, cameras, magnetometers and microphones.[16] The use of smartphones in the tracking and monitoring of many diagnoses continue to grow (eg, dementia, Alzheimer disease, activity levels of cardiac and stroke rehabilitation) as well as in-home care monitoring of sleep apnea, diabetes, and mental disorders.[16] There have been limited studies using applications on smartphones to assess postural stability.[13,17–19] However, the use of a smartphone application could be cost efficient and a readily available sideline tool for the assessment of postural stability in the athletic setting.[28,29] The recent inclusion of relatively sophisticated intertial-measurment technologies in consumer electronical devices is allowing for the opportunity of these devices to objectively assess postural stability in athletes.[17] Two different applications that have been used to assess postural stability are the iPhone Balance Application (IBA) and the SWAY Balance Mobile application (SWAY).[18,19]

The IBA and SWAY application have not been used in studies to assess postural stability after sustaining a SRC. The SWAY application was used in a study to compare results to the BESS in females after anterior cruciate ligament reconstruction. SWAY Balance is an FDA approved iOS mobile software application that enables clinical graded balance testing to be conducted in any setting and is not prone to subjective error.[19] Geddem et al[19] showed no correlation between SWAY Balance and the BESS due to the limited data points and the limited number of subjects. This warrants further research with this application to determine its reliability in assessing postural stability. A recent study done in 2015 was the first to evaluate test-retest reliability of the SWAY balance application.[16] The ICC of the first 3 trials showed that SWAY had good intersession reliability (ICC = 0.61) when compared to that of the other 3 trials (ICC = 0.76).[16] The study showed that the use of trial errors helped reduce the random error.[16] The IBA application was used in a study with individuals suffering from Familial dysautonomia (FD). IBA requires the participant to focus attention on visual environmental cues while maintaining their vertical position, using mainly proprioceptive and vestibular systems in addition to peripheral vision.[18] Based on the findings of Genfen et al,[18] it was suggested that the individuals that trained 2 or 3 times a week for 9 consecutive weeks with the IBA improved in both measures that represented postural stability. Their improvements were retained for 2 months following the initial training without any follow-up.[18]

HEALTH-RELATED QUALITY OF LIFE OUTCOMES (HRQOL)

The value of patient-based measures has become necessary in medical research and evaluation.[46] HRQOL encompasses a person's sense of well-being and satisfaction with their life in terms of physical, psychological, and social functioning, perceptions of self-efficacy, independence, social support, and self-concept.[20] It is important to measure the perception of health of the population to assess the benefit of health care interventions and target services.[21] However, research has shown that existing measures are too narrow, particularly in general practice, to measure the benefit of a wide range of parameters including mobility, functioning, mental health, and over all well-being.[21] HRQOL measures have been developed to assess specific diseases or disabilities, but, are limited when studying people with more than one condition or comparing perceived health across different groups.[21] There are many different assessment tools that can be used for the diagnosis and management of SRC but, neglect the inclusion of the social, emotional and academic issues that may develop postinjury.[47] It has been shown in some studies that a lower HRQOL has been reported for those with a SRC.[20,22] Additionally, HRQOL has been evaluated in military personal that have experienced blast-related traumatic brain injuries to SRCs in civilians. This investigation concluded that those who experienced a traumatic brain injury had a decrease in HRQOL relative to those who sustained a SRC.[48]

Short Form Health Survey (SF-36)

Presently the SF-36 is the most popular generic measure of HRQOL.[46] The questionnaire contains 36 questions covering 8 domains of health status.[46] The 8 domains include: physical functioning, social functioning, role limitations, mental health, vitality, pain, general health perception, and health change.[21] It is a self-administered questionnaire and takes approximately 5 minutes to complete.[21] Due to the short time taken to complete the questionnaire, studies have a response rate of 83% with few incomplete questionnaires.[21] The disadvantage of this scale is that it does not have specific questions for athletes.[22] Advantages are that it is a commonly used tool and can be compared between different groups.[22] There have been studies that investigated athletes and SRC. One study found that adolescent male football players with a self-reported history of SRC had drastically lower HRQOL measures.[22] A similar study using college athletes who had a history of 3 or more SRCs and also demonstrated a lower HRQOL.[22] Valovich et al[49] reported that the concussion group reported significantly lower scores ($P < .008$) on the bodily pain, general health perceptions, vitality, and mental health subscales and on the SF-36 Mental Composite Score. The reliability of the SF-36 has ranged between 0.78- 0.93, reflecting it to be a reliable tool.[22]

Short Form Health Survey (SF-12)

The SF-12 is a 12-item subset of the original 36 items on the SF-36.[21] The developers of the SF-36 suggested that a shorter form health survey that produced the Physical Component Summary Scale (PCS) and Mental Component Summary Scale Score (MCS) without the loss of information from the original survey was needed.[21] The scores can be compared to the national norm score as a mean of 50.0 and a standard deviation of 10.0.[50] The SF-12 contains age-specific mean scores.[50] The SF-36 has proven to be useful but it is too long for inclusion in some large-scale health measurement and monitoring efforts.[51] When comparing the SF-12 to the SF- 36, 3 key points were noted: 1) reproduction of more than 90% of the variance in SF-36 PCS and MCS measured in the general US population; 2) accurate reproduction of average scores for both the SF-36 summary measures, but less accurately for the 8-scale profile; and 3) reduction in length sufficient to print the form on 1 to 2 questionnaire pages and sufficient for self-administration in 2 minutes or less.[51] The SF-12 has shown to be more beneficial in larger sample sizes that have limited time to complete a longer questionnaire.[51]

The SF-12 is shown to be a valid tool when compared to the original SF-36. The only concern is that the SF-12 does not explain 10% of the variance in SF-36 summary scores and is not sensitive on the 8 sub-scales.[51] However, in larger groups the SF-12 and SF-36 proved to be of little importance, because the confidence intervals around group averages were determined more by the sample size.[51] The SF-36 is the better and more reliable tool for smaller sample sizes, whereas the SF-12 is more beneficial with larger sample sizes and when there is a time restraint. [21,51]

Pediatric Quality of Life Inventory (PedsQL)

The PedsQL 4.0 is a modular instrument for measuring HRQOL in children and adolescents ages 2 to 18.[52] This is a multidimensional child self-report scale.[52] These types of measurements need to be sensitive to cognitive development.[52] The PedsQL was recently validated in young adults (5-18 years old).[22] The presence of imperfect concordance suggests a critical need in pediatric HRQOL measurements to be reliable and valid for a broad age range.[52] The questionnaire consists of 23-items divided into 4 domains: 1) physical functioning, 2) social functioning, 3) emotional functioning, and 4) school functioning.[52] Research has shown internal consistency exceeds the standard of 0.70 for group comparison.[52] There have been other studies that have demonstrated that the scale has good internal consistency, test-retest reliability, criterion-related validity, and convergent validity.[22] The PedsQL was demonstrated to have reliability ranging from 0.68- 0.88.[22] In another study it had excellent reliability (0.96) and acceptable validity (0.64).[53] The PedsQL also demonstrated the ability to differentiate between healthy children and those with acute or chronic health conditions.[52,22] The disadvantage of this scale is that it does not contain items specific to athletes.[22]

Chapter 3: Neurocognitive, Postural Stability, and Health-Related Quality of Life Deficits in Secondary School Athletes Without a Clinically Diagnosed Sports-Related Concussion[1]

Context: The affect in secondary school athletes over the course of a football season in those without clinically diagnosed SRCs. Limited research has examined athletes without concussions and effects on neurocognitive, postural stability, and health related quality of life over the course of a collision sport season.

Objective: To determine if neurocognitive, postural stability, and health-related quality of life (HRQOL) changes occur in athletes during the duration of a football season in a secondary school.

Design: Repeated measures design.

Setting: High school football team.

Participants: Thirty-one healthy male football players (15.7 ± 1.17 years, 173.8 ± 11.7 cm, 82.3 ± 22.7 kg) volunteered. To be eligible participants must have been a member of the football team, between the ages of 14 and 18 years, not experiencing signs or symptoms of a concussion, no history of concussion in the 6 months prior to the study, and not currently unable to participate in sports due to an injury.

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[1] This chapter represents a prepublication manuscript to be submitted to the *Journal of Athletic Training* (May 2017). Authors are: Erika K. Lee, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens); Janet E. Simon, PhD, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens); Dustin Grooms, PhD, AT, CSCS (School of Applied Health Sciences and Wellness, Ohio University, Athens); and Bentley A. Krause PhD, AT (School of Rehabilitation & Communication Sciences, Ohio University, Athens).

Data Collection and Analysis: All participants completed the Immediate Post-Concussion Assessment and Cognitive Testing, SWAY Balance mobile application, the Short Form Health Survey, and the Pediatric Quality of Life Inventory during prior to, at midpoint, and following one season of high school football.

Results: Verbal memory decreased between time 1 and time 2 ($\bar{x}_d$ = 5.97)**.** However, reaction time improved between time 1 and time 2 ($\bar{x}_d$ = 0.03), time 1 and 3 ($\bar{x}_d$ = 0.06), and time 2 and 3 ($\bar{x}_d$ = 0.03)**.** The SF-12 MCS, improved between time 1 and time 3 ($\bar{x}_d$ = 5.19) however, the SF-12 PCS and the PedsQL Physical, decreased between time 1 and time 3 ($\bar{x}_d$ = 5.25) and ($\bar{x}_d$ = 9.02), respectively. Overall, SWAY balance score improved between time 1 and time 3 ($\bar{x}_d$ = 8.99)**.**

Conclusion: ImPACT composite scores indicated a decrease between testing points, overall SWAY may be subject to a practice effect during multiple testing points, and HRQOL outcomes showed that with both SF-12 PCS and PedsQL physical domain section that athletes felt a physical decline over the course of a season.

Key Words: concussion, nononcussed, secondary school athletes, neurocognitive, postural stability, health-related quality of life, football, sports

Word Count: 341

Key Points

- ImPACT scores show a decrease between testing points.
- Postural stability measures improved at each testing point.
- HRQOL measures show that athletes feel a decline in their physical health between testing points.

Sport-related concussion (SRC) is a topic that has acquired a growing concern over the past ten years in sports medicine. Diagnosing and managing SRCs are vital to ensuring that clinicians are making the most appropriate return-to-play decisions. This becomes difficult because of the subjective nature of neurocognitive and postural stability testing that has been developed to detect a SRC.[1] The effects of neurocognitive and postural deficits are not always affected to the same degree.[2] Concussions can occur during any sports-related activity; however, the rates of concussions in contact and collision sports are higher than the incidence of other recorded injuries.[3]

American football has gained the most media and scientific inquiry attention in association with SRC, with studies reporting high school football to account for 15-20% of all SRC cases annually.[4] There is increasing concern for collision sports and the effects throughout a season on an adolescent and their developing neurological function. However, there is limited evidence of the neuropsychological effects in athletes who are not clinically diagnosed with a SRC. What type of stress is occurring on the brain in collision sports that entail high repetitions (ie, football)? One study examined participants without a concussion determined that out of the 45 participants, 32 of them showed at least 1 deficit either on the Post-Concussion Symptom Scale, Balance Error Scoring System, or the composite score of ImPACT.[5]Additionally, 19 of those 32 had a change in 2 or more neurocognitive or postural function assessments.[5]

The literature on the effects on the concussed athlete is substantial, but few studies have been done on the neuropsychological effects for an athlete who does not have a clinically diagnosed SRC. It has been theorized that neurocognitive deficits may occur in individuals without a SRC who participate in a collision sport (football) from subconcussive blows. Evaluating neurocognitive, postural stability, and health-related quality of life (HRQOL) prospectively over the course of a high school football season may help understand what neuropsychological changes are occurring in those without a SRC. Sport medicine specialists need to know what is affecting brain function in an uninjured brain during collision sports. Increased knowledge will inform our understanding of brain impairments (neurocognitive and postural stability), as well as with HRQOL outcomes when a SRC is clinically diagnosed. The purpose of this study was to determine if neurocognitive, postural stability, and health-related quality of life (HRQOL) are affected in nonconcussed athletes during the duration of a football season in a secondary school.

METHODS

Participants

Thirty-one healthy male football players (15.7 ± 1.17 years, 173.8 ± 11.7 cm, 82.3 ± 22.7 kg) volunteered. The target population of this study was athletes participating on the football team at Marietta High School. To be eligible for this study, participants were on the football team, between the ages of 14-18, not experiencing signs or symptoms of a concussion, no history of concussion in the 6 months prior to the study, and was cleared for full participation for sports.

Participants were recruited during Ohio High School Athletic Association (OHSAA) meeting held annually at the high school, by the athletic trainer. The participants and their legal guardians read and signed an informed consent form prior to enrollment into the study for data collection. This study was approved by the University's

Institutional Review Board to protect the human subjects who participated in this study (IRB #:16-X-103).

Procedures

All participants were asked to complete a demographic/past medical history questionnaire before any other assessments. Participants reported to the areas where testing was done in Marietta High School for the testing sessions. Data was collected preseason (before the first full-pads practice (August 1, 2016), midseason (October 1, 2016), and postseason (within 48 hours of the last game/ October 29, 2016). All assessments were administered and/or proctored by the primary investigator. Neurocognitive, postural stability, and HRQOL measurements were taken at pre-, mid-, and postseason dates. Neurocognitive testing was done using the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT Applications, Pittsburgh, PA). Postural stability testing was tracked using the SWAY Balance mobile application (SWAY Medical LLC, Tulsa, OK). HRQOL was determined using 2 questionnaires: the Short Form Health Survey (SF-12, Optum, Eden Prairie, MN) and the Pediatric Quality of Life Inventory (PedsQL, PROinformation, rue de la Villette, France). All participants were randomly divided into 3 groups and assigned a different order of testing each time (ImPACT, SWAY Balance app, and HRQOL Questionnaires).

The participants completed the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) administered by the primary investigator in a computer lab at Marietta High School. Testing was done in a quiet room and took approximately 20 minutes to complete for each of the 3 testing sessions. The ImPACT consists of 4 sections: demographic profile and health history questionnaire, current concussion symptoms and conditions, baseline and postinjury neurocognitive tests, and graphic display of ImPACT test scores.

A Post-Concussion Symptom Checklist (PCSCL) was administered within the ImPACT test before and after the testing session to determine if the test had any effect on symptoms during the testing period. The PCSCL consists of 22 different symptoms measured through severity ratings. The PCSCL is distributed with a Likert Scale from 0 to 6 (0-No symptoms, 3-Moderate, 6-Severe). Each participant completed the sections without talking and were only able to ask questions to the primary investigator proctoring the exam. The results were generated into a comparison report for all three testing points with normative values included. The results were then taken from the comparison report and transferred to an excel spread sheet. The excel spread sheet was labeled for each domain of the ImPACT test and for the time during the season taken (pre-, mid-, and postseason). The ImPACT testing has been shown to have a 82% sensitivity when administered within 72 hours of injury.[6] Studies of the effectiveness of ImPACT have reported 89.4% specificity and 81.9% sensitivity.[5]

The participants completed the SWAY Balance Mobile application (SWAY) administered by the primary investigator. The testing took place in a quiet room at Marietta High School and took approximately 15 minutes to complete for each of the 3 testing sessions. The SWAY app was developed by Sway Medical, LLC, and is an FDA approved iOS mobile software application that enables clinical grade balance testing to be conducted virtually in any setting for musculoskeletal, neurological, and vestibular dysfunction. The SWAY application measures thoracic trunk sway using Apple accelerometers to estimate an individual's balance via positional change algorithms. The participants securely held the iPhone at chest height with the screen of device facing towards the body. Participants were allotted 3 trails to practice the test. Individuals were asked to close their eyes with the device held to their chest and stand for 5 positions feet together, single leg on each side, and tandem stance with alternating foot forward for 10 seconds each (see Figure 1). The results were taken from the Apple iPhone and transferred to an excel spread sheet. The excel spread sheet was labeled for the overall score total and at what point during the season each measure was taken (pre-, mid-, and postseason). After each test the scores were presented on a scale of 0-100 with 100 being the most stable and 0 being least.[7] The accelerometer used in the Apple iPhone has demonstrated moderate to good test-retest reliability (ICC = 0.732 to 0.899).[8]

Figure 1. SWAY Balance Mobile application stances.

The participants completed the Short Form Health Survey (SF-12) and the Pediatric Quality of Life Inventory (PedsQL) administered by the primary investigator. The testing took place in the lunchroom at Marietta High School and took approximately

20 minutes to complete for each of the three testing sessions. Participants were asked to complete the surveys to the best of their ability without any help. The SF-12 is a multipurpose, short-form health survey consisting of 12 questions. With an 8-Scale profile of functional health and well-being scores. The results for the SF-12 was transferred to an excel spread sheet that was labeled for the two summary scores and the for each time point. The test-retest reliability of the SF-12 summary measures have been shown to good (0.89 for the Physical Component Summary Score (PCS) and 0.76 for the Mental Component Summary Score (MCS)).[9] All participants completed the PedsQL at the three time points. The testing was administered in the lunchroom at Marietta High School. The test takes approximately 4 minutes to complete. The PedsQL integrates seamlessly both generic core scales and disease-specific modules into one measurement system. The PedsQL is a 23-item questionnaire that access the subjects' physical (8 items), emotional (5 items), social (5 items), and school functioning (5 items). The PedsQL was distributed at three points during the 2016 football season (pre-, mid-, and postseason). The results for the PedsQL was transferred to an excel spread sheet that was labeled for each of the four domains, and the score received at each time point in the season (pre-, mid-, and postseason). Reliability for the PedsQL in healthy individuals between the ages of 13-18 years is 0.91 with the child self-report at 0.92.[10,11]

Statistical Analysis

The dependent variables were Verbal Memory Composite, Visual Memory Composite, Visual Motor Composite, Reaction Time Composite, Impulse Control Composite, and Total Symptom Score of the ImPACT, SF-12 PCS, SF-12 MCS, PedsQL Physical, PedsQL Emotional, PedsQL Social, and PedsQL School scales, and the overall score on the SWAY Balance. The independent variable was time (pre-, mid-, and postseason). Two multivariate repeated measures ANOVAs were conducted. The first multivariate ANOVA consisted of the ImPACT variables (Verbal Memory Composite, Visual Memory Composite, Visual Motor Composite, Reaction Time Composite, Impulse Control Composite, and Total Symptom Score). The second multivariate repeated measures ANOVA consisted of the HRQOL variables (SF-12 PCS, SF-12 MCS, PedsQL Physical, PedsQL Emotional, PedsQL Social, and PedsQL School). If the multivariate ANOVA is significant for time, follow up univariate ANOVAs were conducted for each dependent variable. Additionally, a univariate ANOVA was conducted for the Overall SWAY Balance score. Alpha level was set at $P < 0.05$ for all analyses.

RESULTS

ImPACT

The multivariate repeated measures ANOVA was significant for time ($F_{(12,19)}$ = 2.49, $P = 0.03$). Follow up one-way repeated measures ANOVAs were conducted for the six dependent variables of the ImPACT testing (Verbal Memory Composite, Visual Memory Composite, Visual Motor Composite, Reaction Time Composite, Impulse Control Composite, and Total Symptom Score). The follow up ANOVAs indicated three dependent variables were significant for time. Verbal Memory ($F_{(2)} = 3.67$, $P = 0.03$, $1\text{-}\beta = 0.65$), significantly decreased between time 1and time 2 ($\bar{x}_d = 5.97$)**.** Reaction Time ($F_{(2)} = 10.01$, $P = 0.001$, $1\text{-}\beta = 0.98$), significantly improved between time 1 and time 2 ($\bar{x}_d$ = 0.03), time 1and 3 ($\bar{x}_d = 0.06$), and time 2 and 3 ($\bar{x}_d = 0.03$)**.** The final variable that was found to be significant was Impulse Control ($F_{(2)} = 4.96$, $P = 0.01$, $1\text{-}\beta = 0.79$), that significantly decreased from time 1and time 3 ($\bar{x}_d = 3.62$). Visual Motor, Visual Memory, and Symptom Score were all found to be not significant ($P > 0.05$). Table 1 contains the means and standard deviations for all ImPACT variables.

Table 1. Descriptive Statistics for ImPACT Variables at Each Time Point

	Time 1	Time 2	Time 3
Verbal memory	83.03 ± 9.21	77.06 ± 13.58*	79.25 ± 12.76
Visual memory	67.13 ± 11.57	65.71 ± 16.71	65.06 ± 17.00
Visual motor	34.45 ± 5.99	35.12 ± 7.35	34.83 ± 8.60
Reaction time	0.66 ± 0.08	0.63 ± 0.07*	0.60 ± 0.06†‡
Impulse control	6.54 ± 4.53	8.45 ± 6.18	10.16 ± 8.89†
Symptom score	3.48 ± 5.72	3.67 ± 4.70	3.29 ± 8.69

*Significant difference between time 1 and time 2 ($P < 0.05$).
†Significant difference between time 2 and time 3 ($P < 0.05$).
‡Significant difference between time 1 and time 3 ($P < 0.05$).

HRQOL

The multivariate repeated measures ANOVA was significant for time ($F_{(6,12)} = 7.38$, $P = 0.001$). Follow up one-way repeated measures ANOVA were conducted for the six HRQOL dependent variables. The follow up ANOVA's indicated three dependent variables were significant for time. The SF-12 MCS ($F_{(2)} = 7.46$, $P = 0.001$, $1\text{-}\beta = 0.93$), significantly improved between time 1 and time 3 ($\bar{x}_d = 5.19$). The SF-12 PCS ($F_{2)} = 6.59$, $P = 0.003$, $1\text{-}\beta = 0.89$), significantly decreased between time 1 and time 3 ($\bar{x}_d = 5.25$). Finally, the PedsQL Physical ($F_{(2)} = 3.86$, $P = 0.02$, $1\text{-}\beta = 0.67$), significantly decreased between time 1 and time 3 ($\bar{x}_d = 9.02$)**.** PedsQL Emotional, PedsQL Social, and PedsQL School found to be not significant ($P > 0.05$). Table 2 contains the means and standard deviations for all HRQOL variables.

Table 2. Descriptive Statistics for HRQOL Variables at Each Time Point

	Time 1	**Time 2**	**Time 3**
SF-12 MCS	51.16 ± 6.24	54.13 ± 6.13	56.35 ± 5.36*
SF-12 PCS	54.77 ± 6.29	51.12 ± 6.25	49.52 ± 6.03*
PedsQL Physical	95.51 ± 7.85	93.04 ± 22.51	86.49 ± 10.19*
PedsQL Emotional	88.71 ± 15.05	91.45 ± 14.09	94.19 ± 9.23
PedsQL Social	91.13 ± 12.36	90.16 ± 13.44	95.00 ± 9.31
PedsQL School	77.74 ± 17.07	80.32 ± 17.81	83.55 ± 15.51

*Significant difference between time 1 and time 3 ($P < 0.05$).

SWAY Balance

A one way repeated measures ANOVA was conducted for the overall SWAY balance score. Overall SWAY balance score was significant for time ($F_{(2)} = 8.05$, $P = 0.001$, $1-\beta = 0.948$), with a significant improvement between time 1 and time 3 ($\bar{x}_d = 8.99$)**.** Table 3 contains the means and standard deviations for the Overall Sway Score.

Table 3. Descriptive Statistics for Overall Sway Balance at Each Time Point

	Overall Sway Score
Time 1	65.59 ± 8.78
Time 2	69.13 ± 14.79
Time 3	74.58 ± 8.52*

*Significant difference between time 1 and time 3 ($P < 0.05$).

DISCUSSION

The results of this study indicated that the ImPACT showed to have increased score in the reaction time, and decreased scores on the Impulse Control and Verbal Memory Composites. The SWAY overall total score for this study improved over time. At each of the 3 testing point participants increased their scores. Lastly, this study found that the scores of the SF-12 MCS improved, but the SF-12 PCS decreased between time 1 and time 3. This may warrant a concern because if individuals participating in athletics are showing a decrease in physical functioning then they may be at a greater increase for obtaining not only a SRC but, other sports-related injuries. The results of this study for the PedsQL were like the SF-12 PCS, with a decrease in the physical functioning scale.

Immediate Post-Concussion Assessment and Cognitive Testing

The drawback of the ImPACT is that it can be costly but, has been shown to be effective in determining if a patient is experiencing neurocognitive symptoms.[3] It has been shown that the use of an athlete's own baseline is more accurate then matching them with same age and sport normative data.[12] Table 4 and 5 show the normative data of ImPACT for male athletes with no impairments ages 13-15 and 16-18, respectively.[13]

Table 4. Normative Data for High School Males Ages 13-15

	Verbal Memory	**Visual Memory**	**Processing Speed**	**Reaction time**
Impaired	≤ 63	≤ 49	≤ 16.2	≥ .76
Borderline	64-73	50-60	16.3-24.2	.75-.67
Below average	74-79	61-68	24.3-30.1	.66-.61
Average	80-92	69-86	30.2-37.8	.60-.53
High average	93-96	94-97	37.9-44.2	.52-49
Superior	97-99	94-97	44.3-50.2	.48-.45
Very superior	100	98-100	≥ 50.3	≤ .44

Table 5. Normative Data for High School Males Ages 16-18

	Verbal Memory	**Visual Memory**	**Processing Speed**	**Reaction Time**
Impaired	≤ 68	≤ 51	≤ 26.4	≤ .74
Borderline	69-74	52-59	26.5-29.6	.73-.64
Below average	75-79	60-70	29.7-33.6	.63-.59
Average	80-92	71-88	33.7-42.5	.58-.50
High average	93-98	89-93	42.6-47.7	.49-.47
Superior	99	94-96	47.8-51.1	.46-.43
Very superior	100	97-100	≥ 51.2	≤ .42

The Verbal Memory Composite score consists of the average scores of these subcategories: [Word Memory total percent correct (immediate + delay) / 2, symbol Match (hidden symbols)/9*100], and Three Letters Total letters correct. The higher score indicates a better performance. [13] The Verbal Memory Composite score was found to have a significant decrease between time 1(83.03 ± 9.21) and time 2 (77.06 ± 13.58). When compared to the normative scores in Table 4 and Table 5, between time 1 (preseason) and time 2 (midseason) the athletes went from average to below-average level. This was consistent with other studies that also found a decrease between different testing points within a season.[14] Talavage et al[15] unexpectedly found that 4 of 8 clinically observed impairment players evaluated during the season, and were not exhibiting symptoms that would prompt an evaluation for a concussion by the team healthcare professionals, were found to have a statistically significant decrease in ImPACT scores (Verbal Memory Composite).[15] A study conducted by Lovell et al[14] showed that concussed high school athletes had decreased scores for the Verbal Memory Composite.

The Visual Memory Composite score consists of the average scores of these subcategories: [Xs and 0s Total correct (memory)/12*100], and [design memory-total percent correct (immediate + delay) / 2]. The higher the score in this section of the ImPACT indicates better performance.[13] For this study this section of the ImPACT yielded no statistical findings but, participants scored within normative values. However, in a study done by Talavage et al[15] showed that half of the participants that had been evaluated during season, elicited no symptoms that would warrant further concussion evaluation by the team's medical staff, showed to have a decrease between preseason and in-season testing. But, postseason scores returned to relative baseline levels. Also, found in a recent study done in 2016 by Maerlender et al[16] both Memory Composite score was subject to an increase in scores between the 4 administrations of the test. This also suggests that this composite score of ImPACT is subject to a learning effect when administered at multiple points.[16] Although this current study did not elicit any significant findings in this section it is important to note that there may be an increase in baseline scores when repeatedly administered.

The Visual Motor Composite consists of the average scores of these subcategories: [X's and O's (average correct distracters), Symbol Match (average correct responses), and Three letters (number of correct numbers correctly counted)].[13] For this current study there were no significant statistical findings between testing points and participants had average scores when compared to normative values. Though this study did not find any changes in the Visual Motor Composite other studies showed participants improving in this area of ImPACT when retaking the evaluation multiple times. A study by Register-Mihalik et al[17] done in 2012 examined age and practice effects of ImPACT though their sample size was relatively small (N = 20 for each cohort). They found that the Visual Motor Composite was significantly different in the collegiate group at each of the 3 points. Performance between times 1 and 2 showed the greatest improvement; across the 3 tests there was a 35% change.[17]Another study conducted by Schatz and Ferris[3] also showed a significant improvement during a 25-day retest of 25 college aged participants. However, a study done by Iverson et al[14] that used a much larger sample size had no improvements in the Visual Motor score.

Reaction Time Composite is the combined average score of these subcategories: Xs and 0s average correct RT, Symbol Match average correct RT/3, and Color Match average correct RT.[13] A lower score is indicative of better performance.[13] In the present study, reaction time improved significantly between time 1 and time 2 (pre- to midseason), time 1 and 3 (pre- to postseason), and time 2 and 3 (mid- to postseason)**.** For pre- and midseason testing points, participants went from below to average scores when compared to the normative scores of high school boys between the ages of 13-15; therefore, their performance improved between each time point. In contrast, high school boys between ages 16-18 increased from borderline to below-average (improving their scores), but never performed above average. Pre-and postseason testing points showed that those between the ages of 13-15 improved their scores but remained in the below-average testing range. Those in the age range 16-18 also improved their scores between pre- and postseason, increasing from borderline to below-average. Finally, at mid- and postseason testing points those ages 13-15 increased from below-average scores to average scores. But, those ages 16-18 stayed below-average even with improving their times between each point. Del Rossi et al[18] examined reaction time with multiple testing points using a 60-cm long stick. They found that reaction times decreased between each testing point, implicating that participants improved each time.[18] This shows that reaction time can be susceptible to a practice effect over multiple testing points.

The Impulse Control Composite score consists of the sum of the following subcategory scores: Xs and 0s-total incorrect interference, and color match total commissions.[14] For this section a low score indicates a better performance. [13] This score indicates the sum of errors committed during certain aspects of the test.[13] A high score (above 20) may suggest carelessness in completing ImPACT. A very high score (above 20), may suggest confusion between left and right, as measured by the Total Correct-Interference score from the Xs and Os module. [13] For this study, Impulse Control was significantly worse between time 1 (6.54 ± 4.53) and time 3 (10.16 ± 8.89)**.** A higher score on Impulse Control is worse, overall scores increased 3.62 points. A study done by

Maerlender et al[16] indicated that there was no change in these scores between multiple testing points; therefore, this composite score shows to be more reliable. When compared to the present study it may indicate that participants took the testing less seriously by the final testing point, indicating a poorer performance between time 1 and time 3.

The Total Symptom Score of the PCSCL did not show any statistically significant change in this study. Nevertheless, participants stated they were experiencing symptoms with a mean of 3.48, indicating that healthy individuals may be experiencing symptoms related to post-SRC symptoms. Typical symptoms that are associated with post-SRC include headaches, memory and concentration problems, dizziness, anxiety, insomnia, depression, irritability, fatigue, and sensitivity to light and noise.[19] A study conducted by Raymond et al[19] examined healthy individuals without a SRC and their rate of SRC symptoms. They determined that a mean average score of symptoms experienced was 9.49 on the PCSCL.[19] This may warrant concern as healthy individuals experience symptoms similar to those that have sustained a SRC.

SWAY Mobile Balance Testing: Overall Balance Score

Using smartphones to assess balance has become increasingly popular with the advancement of technology.[20] However, there have been limited studies about using smartphones to assess balance.[7,8,21,22] To the knowledge of the researcher, this is the first study to use the SWAY Mobile Balance application to determine postural deficits in secondary school football players without a clinically diagnosed SRC over the course of a single season. This study indicated that the overall SWAY score improved between time 1 (65.59 ± 8.78) and time 3 (74.58 ± 8.52)**.** This could indicate that the SWAY Mobile Balance application is subject to a learning effect when administered at multiple testing points. Other postural stability measures have also elicited a learning effect when administered multiple times.[16,18,23–25] One of the more common balance assessments, the Balance Error Scoring System (BESS) has been shown to have a learning effect. Valovich et al[24] investigated the possibility of a practice effect for the SAC and the BESS. They found that after practicing the BESS every day there was a learning effect after 5 and 7 days (less errors on the exam compared to baseline). [24]

Another concern is that there is a greater practice effect for activities that are unusual or entail different senses or movements. This has been shown in a study by Valovich et al[24] who looked at the practice effect of the Star Excursion Balance Test.[24] They determined that the largest factor of the documented improvement was coping with impaired visual feedback, concluding that the more difficult the task the more of a learning effect is seen.[24] The biggest concern when identifying a learning effect is how to distinguish between improvements in postural sway or improvements that are possibly caused by a learning effect.[24] This is the primary concern with the SWAY application as it involves a novel task for a majority of the individuals in this study. Therefore, there needs to be future research to determine if a learning effect is documented when utilizing the SWAY to assess postural control.

Health-Related Quality of Life Outcomes

There are many different assessment tools that can be used for the diagnosis and management of SRC but many neglect the inclusion of social, emotional and academic issues that may develop postinjury.[26] It has been shown that existing measures are too narrow, particularly in general practice, to measure the benefit of a wide range of parameters including mobility, functioning, mental health, and over all well-being.[27]

There needs to be a measure of HRQOL that has been developed to assess deficits in athletes. This study utilized the SF-12 and the PedsQL to determine if there would be a change in HRQOL for secondary school athletes during a football season without a clinically diagnosed SRC.

While prospective studies regarding the impact of concussion on HRQOL are limited, both adolescent and adult athletes with a history of a concussion have reported HRQOL deficits on the SF-36 and HIT-6. [26] Valovich et al[28] reported that on the SF-36, those with a concussion reported significantly lower scores ($P < .008$) on the bodily pain, general health perceptions, vitality, and mental health subscales and on the SF-36 Mental Composite Score. No differences were noted on the physical functioning, role physical, social functioning, and role emotional subscales or the Physical Composite Score.[28] Adolescents with a self-reported concussion history demonstrated lower HRQOL on several SF-36 subscales, including those related to mental health, and a greater impact of headache on their general health.[28] Lower scores on the bodily pain, general health perceptions, vitality, mental health subscales, and the Mental Composite Score represent perceived deficits in these domains of HRQOL in adolescents with previous concussion.[28] However, no current studies, to the knowledge of the authors, utilized the short form health surveys in secondary school football athletes who have not sustained a SRC. The scoring of PCS and MCS of the SF-12 use a normative scoring metric with a mean score of 50.0 and a standard deviation of 10.0.[29] The results of the present study indicate that the SF-12 MCS, significantly increased between time 1 (51.16 ± 6.24) and time 3 (56.35 ± 5.36)**.** Compared to the national normative value of 50.0, participants in this current study scored above the normative score at preseason and improved the score by 0.5 standard deviation by postseason. One possible reason an increase in the MCS was seen is that the football season had finished and there was less pressure to perform. Another possible reason is that the participants were mostly underclassman who had not participated in football for a few weeks due to the conclusion of their schedule. The SF-12 PCS, was found to significantly decrease between time 1 (54.77 ± 6.29) and time 3 (49.52 ± 6.03). When compared to the normative national score of 50.0 participants at preseason scored almost 0.5 a standard deviation above the normative value; however, at postseason their score decreased but not significantly below the normative national score. The decrease in the PCS score may have occurred because the participants were physically taxed over the course of the football season. The preseason testing was collected prior to any participation and the postseason scores concluded following 24-48 hours after the final scheduled varsity game. Therefore, the participants may have been physically drained from the 3-month season of practices and games.

Similar to the SF-12, the PedsQL does not contain specific items for athletes and is the main limitation for its use.[17] There have been very few studies that have used the PedsQL as a tool for concussion management. One particular study by Houston et al[26] found that HRQOL measures were associated with time lost following a concussion. Also, it was found that the PedsQL can have a predictive utility.[26] The PedsQL physical and school scores accounted for 17.9% and 15.2% of the variance in time lost at day 3 and day 10 following a SRC.[26] Houston et al[26] also found that the PedsQL school and cognitive domains were related to time lost and may further demonstrate the utility of HRQOL measures for assessing the patient's perspective to ensure that adequate cognitive rest and academic adjustments are built into the concussion management plan.[26]

The results of our study indicated that the PedsQL physical domain significantly decreased between time 1 (95.51 ± 7.85) and time 3 (86.49 ± 10.19). Though there was not a large difference between preseason and postseason scores, participants decreased (9.02 points) from the preseason values. This could indicate that the athletes felt a physical decline by the end of the football season compared to before season; these results also are supported in the decline seen on the SF-12 PCS score.

Limitations

This study has several limitations. Specifically, the small convenience sample, the use of only male athletes, and only one single contact sport (football) limits the generalizability. This study only used healthy individuals versus those with a SRC. The SWAY Mobile Balance application is only available for use with Apple devices that have iOS. The SWAY also might not be cost effective for some individuals as it requires a subscription to use and cost per user. Also, there were multiple administrators of the SWAY which could increase the variation among scores. Lastly, the HRQOL measures utilized were not specifically developed for athletes.

Further Research

Future research should consider the development of a specific HRQOL measure for athletes with a SRC. Also, determining if the SWAY Balance Mobile application has a learning effect when administrated at multiple testing sessions is important if the SWAY is to be used in the clinical setting. Finally, the determination of a true learning effect in the Memory Composite scores of the ImPACT is needed.

CONCLUSION

This study showed that the ImPACT test had composite scores that significantly changed over the course of a football season. The Verbal Memory Composite decreased, indicating that participants declined throughout the season. Reaction time decreased, which indicates an improvement was seen over the course of a season. The overall SWAY scores increased at each testing time point; this is consistent with other postural stability studies that have shown a practice effect with multiple testing points. The SF-12 PCS and the PedsQL Physical domain scores decreased over the course of the season, which may be an indication of physical taxation from the season. This study indicates that there are deficits shown in healthy athletes over the course of a single football season. Future studies need to be conducted to consider changes that are occurring to healthy athletes over the course of a competitive sports season.

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Chapter 4: Conclusion

This study indicated that during a season healthy high school aged football players, not eliciting signs or symptoms of a SRC, have deficits in components of a neuropsychological exam over the course of a season. The ImPACT showed decreased Verbal Memory and Impulse Control Composite scores, and an increase for the Reaction Time Composite. For this study, the results for the Verbal Memory Composite score coincided with other studies that indicated a decrease in verbal memory when tested in healthy individuals. This also warrants concern that deficits are being seen with this composite score, because this area of the brain is responsible for working memory. The reaction time decreased between testing times indicating an improvement in participants' reaction. The Impulse Control Composite showed increased scores, indicating that the participants may have been careless with the test by the final testing point.

The SWAY overall total score for our participants improved over time. At each of the 3 testing points, participants increased scores. Though this area did not decrease during the duration of a season, SWAY application warrants further research to determine if these healthy athletes experience deficits by using multiple balance tools. Also, this is a concern because there may be a possible learning effect with this tool.

This study, found that the scores of the SF-12 MCS improved, but the SF-12 PCS and the PedsQL physical component showed a decline between time 1 and time 3. This raises the concern that if athletes are feeling a decline in physical functioning, this can put them at a greater risk for having not only a SRC but also other sports-related injuries.

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Appendix: A Specific Aims

Concussions have become a vast growing topic of interest in the field of sports medicine. Making it important for clinicians to be sure that they are making the most appropriate return to play decisions. No two concussions are the same, the effects of neurocognitive and balance deficits are not always effected at the same degree.[6] Many of studies have taken into account the effects of the concussed athletes, but little has been looked at in those without a clinically diagnosed concussion and the effects of repetitive blows to a football athlete in a single season.

It is important to investigate what is happening to athletes when competing in contact sports that involve tackling, being taken to the ground and possibly sustaining repetitive blows to the head. This will help researchers, clinicians, athletes, and parents understand if there are any longitudinal changes happening to the brain throughout a single collision sport season. Sports medicine personnel need to have the best knowledge of what is effecting brain function in the normal brain and with repetitive blows to help get a better understanding of the possible effects on the brain.

There is no “gold standard” to assess the effects of repetitive blows on brain function. However, there is an increased emphasis in the literature to assess brain function from a well-rounded approach. This includes assessment of neurocognition, postural stability, and health-related quality of life (HRQOL). Computerized neurocognitive assessments are becoming the preferred means of testing neurocognitive deficits, often they are based on the traditional neuropsychological tests, to measure verbal memory, visual design memory, concentration, visual processing speed, and reaction time. Postural stability has been defined as ones’ ability to maintain control of their center of gravity or equilibrium within the limits of stability, over a base of support. This is maintained primarily through three different sensory inputs: vision, somatosensory, and vestibular. The use of smartphones in the tracking and monitoring of many diagnoses has been continuing to grow, these include: dementia, Alzheimer disease, activity levels of cardiac and stroke rehabilitation, as well as in home care monitoring of sleep apnea, diabetes, and mental disorders. There have been limited studies on the use of applications on a smartphone for the assessment of postural stability. But, this could be seen to be a beneficial, cost efficient and readily available sideline tool for the assessment of postural stability in the athletic setting. Health-related quality of life measures have been a critical component in patient care for a variety of injuries, disorders, and illnesses. The concept collaborate a person’s sense of well-being and satisfaction with their life in terms of physical, psychological, and social functioning, perceptions of self- efficacy; independence; social support; and self- concept. By approaching this research study from a holistic approach (clinical measures and HRQOL) the researchers hope to fill a void in the current literature by understanding the effects of a single football season on neurocognition, postural stability, and HRQOL.

The goal of this research are to investigate whether there are neurocognitive, postural stability, or HRQOL deficits over the course of a single season in athletes

participating in football, a high collision contact sport, in those who have not sustained a clinically diagnosed sports-related concussion.

<u>The following are the specific aims for the research study:</u>

Aim 1: To determine if neurocognitive changes will occur over the course of a football season in secondary school athletes without a clinically diagnosed with a concussion.

1.1 Neurocognitive changes will be determine through the collection of preseason, midseason, and postseason measurements using Immediate Post- Assessment and Cognitive testing(ImPACT) and Post-concussion Symptom Scale.

Aim 2: To determine if motor function (ie. postural stability) will be effected of the course of a football season in secondary school athletes without a clinically diagnosed with a concussion.

3.1 Postural stability changes will be determined through the collection of preseason, midseason, and postseason measurements using the SWAY app through an iphone.

Aim 3: To determine if HRQOL measurements will be effected over the course of a football season in secondary school athletes without a clinically diagnosed with a concussion.

c. HRQOL changes will be determined through the collection of preseason, midseason, and postseason measurements using the Short Form-12 (SF-12) and Pediatric Quality of Life Inventory (PedsQL).

Appendix B: Data Procedure Checklist

- Recruitment
  - During annual football meetings at start of season
  - Explain study answer any questions for participants/ guardians
  - Signed informed consent/ assent forms
- Demographic/ History Questionnaire
  - Each participant will fill these out prior to start of the data collection
- Check for inclusion/ exclusion criteria
- Randomly place participants into 3 testing groups
  - Each group will start at one of the three testing stations (ImPACT, SWAY, or HRQOL surveys)
  - At each testing point (preseason, midseason, and postseason) the groups will be placed at a different starting station
- Complete Immediate Post-Concussion Assessment and Cognitive Testing
  - Asked to start the test fill out all questions to the best of their abilities
  - If participants have any questions they are to direct them to the research investigator at this testing station.
- Complete SWAY Balance Mobile Application
  - Asked to complete 5 different stance with smartphone device held to their chest with screen facing forward.
  - They will have three practice trials and the fourth one will count
  - They will stand in each stance for 10 seconds and 30 seconds between each trial.

  - If the participants have any questions they are to direct them to the research investigator at this testing station.
  - Stance 1: Feet together
  - Stance 2: Tandem stance left foot forward
  - Stance 3: Tandem stance right foot forward
  - Stance 4: Single leg standing on left foot
  - Stance 5: Single leg stance standing on right foot
- Complete Health-Related Quality of Life Surveys: SF-12 and PedsQL
  - Will be handed each survey and asked to read direction if they have any question to direct them to the research investigator assigned to this station.
- All testing will be completed at three points
  - Preseason (August 1, 2016)
  - Midseason (October 1, 2016)
  - Postseason (October 29, 2016)

Appendix C: Data Collection Forms and Surveys

	Memory Composite (verbal)	Memory Composite (visual)	Visual Motor Speed Composite	Reaction Time Composite	Impulse Control Composite	Total Symptom Score
ID#						

ImPACT SWAY

	Feet Together	Tandem Stance Left Foot Forward	Tandem Stance Right Foot Forward	Single Leg Stance Left Foot	Single Leg Stance Right Foot
ID#					

ImPACT SWAY

ID#:_____________

Demographic/ Past History Questionnaire

Please do not put your name on this questionnaire. Please answer the following questions honestly and to the best of your ability.

Year of school:

Senior Junior Sophomore
Freshman

How old are you? ___________________________

Level of Participation: (circle all that apply)

Freshman Junior Varsity Varsity

How many years of football have you played? (Including pee wee)

____

What position/s do you play?

____

Have you ever sustained a blow to the head while playing football?

Yes No

Approximately how many number of times are you hit in the head during participation in football? ____

Have you ever been diagnosed with a concussion by a medical professional?

Yes No

Have you ever suspected you had a concussion and did not report it?

Yes No

How many concussions have you had? _______________

When you tackle another player how often do you lead with your head?

Always Often Sometimes Never

SF-12® Questionnaire **ID#__________**

Answer every question by placing a check mark on the line in front of the appropriate answer. If you are unsure about how to answer a question, please give the best answer you can and make a written comment beside your answer.

1. In general, would you say your health is:

_____ Excellent (1)

_____ Very Good (2)

_____ Good (3)

_____ Fair (4)

_____ Poor (5)

The following two questions are about activities you might do during a typical day. Does YOUR

HEALTH NOW LIMIT YOU in these activities? If so, how much?

2. MODERATE ACTIVITIES, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf:

_____ Yes, Limited A Lot (1)

_____ Yes, Limited A Little (2)

_____ No, Not Limited At All (3)

3. Climbing SEVERAL flights of stairs:

_____ Yes, Limited A Lot (1)

_____ Yes, Limited A Little (2)

_____ No, Not Limited At All (3)

During the PAST 4 WEEKS have you had any of the following problems with your work or other regular activities AS A RESULT OF YOUR PHYSICAL HEALTH?

4. ACCOMPLISHED LESS than you would like:

_____ Yes (1)

_____ No (2)

5. Were limited in the KIND of work or other activities:

_____ Yes (1)

_____ No (2)

During the PAST 4 WEEKS, were you limited in the kind of work you do or other regular activities AS A RESULT OF ANY EMOTIONAL PROBLEMS (such as feeling depressed or anxious)?

6. ACCOMPLISHED LESS than you would like:

_____ Yes (1)

_____ No (2)

7. Didn’t do work or other activities as CAREFULLY as usual:

_____ Yes (1)

_____ No (2)

8. During the PAST 4 WEEKS, how much did PAIN interfere with your normal work (including both work outside the home and housework)?

_____ Not At All (1)

_____ A Little Bit (2)

_____ Moderately (3)

_____ Quite A Bit (4)

_____ Extremely (5)

The next three questions are about how you feel and how things have been DURING THE PAST 4 WEEKS. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the PAST 4 WEEKS –

9. Have you felt calm and peaceful?

_____ All of the Time (1)

_____ Most of the Time (2)

_____ A Good Bit of the Time (3)

_____ Some of the Time (4)

_____ A Little of the Time (5)

_____ None of the Time (6)

10. Did you have a lot of energy?

_____ All of the Time (1)

_____ Most of the Time (2)

_____ A Good Bit of the Time (3)

_____ Some of the Time (4)

_____ A Little of the Time (5)

_____ None of the Time (6)

11. Have you felt downhearted and blue?

_____ All of the Time (1)

_____ Most of the Time (2)

_____ A Good Bit of the Time (3)

_____ Some of the Time (4)

_____ A Little of the Time (5)

_____ None of the Time (6)

12. During the PAST 4 WEEKS, how much of the time has your PHYSICAL HEALTH OR EMOTIONAL

PROBLEMS interfered with your social activities (like visiting with friends, relatives, etc.)?

_____ All of the Time (1)

_____ Most of the Time (2)

_____ A Good Bit of the Time (3)

_____ Some of the Time (4)

_____ A Little of the Time (5)

_____ None of the Time (6

PedsQL ID#____________

In the past **ONE month**, how much of a problem has this been for you…….

ABOUT MY HEALTH AND ACTIVITIES (problems with…)	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1.It is hard for me to walk more than a block	0	1	2	3	4
2.It is hard for me to run	0	1	2	3	4
3.It is hard for me to do sports activity or exercise	0	1	2	3	4
4.It is hard for me to lift something heavy	0	1	2	3	4
5.It is hard for me to take a bath or shower by myself	0	1	2	3	4
6.It is hard for me to do chores around the house	0	1	2	3	4
7.I hurt or ache	0	1	2	3	4
8.I have low energy	0	1	2	3	4
ABOUT MY FEELINGS (problems with..)	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1.I feel afraid or scared	0	1	2	3	4
2.I feel sad or blue	0	1	2	3	4
3.I feel angry	0	1	2	3	4
4.I have trouble sleeping	0	1	2	3	4
5.I worry about what will happen to me	0	1	2	3	4

HOW I GET ALONG WITH OTHERS (problems with…)	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1.I have trouble getting along with other teens	0	1	2	3	4
2.Other teens do not want to be my friend	0	1	2	3	4
3.Other teens tease me	0	1	2	3	4
4.I cannot do things that other teens my age do	0	1	2	3	4
5.It is hard to keep up with my peers	0	1	2	3	4
ABOUT SCHOOL (problems with…)	**Never**	**Almost Never**	**Some-times**	**Often**	**Almost Always**
1.It is hard to pay attention in class	0	1	2	3	4
2.I forget things	0	1	2	3	4
3.I have trouble keeping up with my schoolwork	0	1	2	3	4
4.I miss school because of not feeling well	0	1	2	3	4
5.I miss school to go to the doctor or hospital	0	1	2	3	4

Appendix D: Instrument Reliability

Instrument reliability will be presented at the Thesis proposal presentation. A hard copy of the data will be provided to each committee member.

Appendix E: Power Analysis

Contrary to a traditional power analysis the whole population of football players at Marietta High School will be used. An approximation of 150 football players will be participating in this study

Appendix F: Pilot Data

The following is pilot data for three individuals. All individuals were male, age 15.3±1.5 (14-17) years; two of them were freshman and one junior. The following tables display the data for the three individuals.

ImPACT Composite Scores

Participant	Memory Verbal	Memory Visual	Visual Motor Speed	Reaction Time	Impulse Control	Total Symptom
1	80	67	25.63	0.62	5	46
2	81	50	34.48	0.74	9	22
3	79	76	31.38	0.63	10	0

SWAY Overall Balance Score

Participant	Balance Overall Score
1	60.09
2	63.76
3	78.81

HRQOL Measures

Participant	SF-12 MCS	SF-12 PCS	PedsQL Physical	PedsQL Emotional	PedsQL Social	PedsQL School
1	50.1	50.7	78.13	80	100	65
2	32.1	65.6	71.87	100	95	55
3	55.2	57.8	100	100	65	65

Appendix G: Signed Approval Letter

MARIETTA HIGH SCHOOL

Institutional Review Board Committee

Office of Research Compliance

Research and Technology Center 317

Ohio University

Athens, Ohio 45701

Dear Review Committee,

I am writing to express my enthusiastic support for our Marietta's High School Graduate Assistant Athletic Trainer to serve as primary researcher and allowing my facility as a data collection site for faculty and students from Ohio University's Athletic Training Department. The research project, *Neurocognitive, Postural Stability, and HRQoL Deficits in Secondary Athletes Without a Clinically Diagnosed Concussion*, shows to be an exceptional and exciting project, and has the potential to make a significant impact in sports medicine research, specifically in the athlete without a diagnosed concussion in high school football players through the course of a single season.

I am aware that Ohio University's primary researcher will do all the data collection for the study. I recognize that the recruitment process will take place during the annual fall OHSAA meeting by the primary researcher. I will not answer any questions in regards to the research study instead; however I will refer the questions to the appropriate research team member at Ohio University.

Sincerely,

Richard Guimond

Marietta High School Athletic Director

"Opening Doors to a World of Opportunities"

115 Academy Drive, Marietta, OH 45750-1417 ★ 740/374-6540 ★ Fax 740/376-2462