Impact of Sports-Related Subconcussive Injuries in Soccer Players

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ABSTRACT

Sports-related subconcussive impacts to the head are receiving increased interest. Recent evidence indicates that subconcussive impacts will have greater relevance across time because of the number of repetitive impacts. Soccer players are at risk of receiving at least one impact during a soccer game. The authors review the cognitive-communication functioning following subconcussive head injuries in youth and recommendations for baseline assessments and cognitive-communication dysfunctions after subconcussive impacts in youth. The review is followed by a description and discussion of a study that assessed the cognitive-communicative dysfunction in young soccer players prior to and following a series of soccer matches and recommendations for monitoring recovery of cognitive-communication.

KEYWORDS: subconcussive impacts, neurocognitive assessment, pediatrics, adolescent, adult, mTBI

Learning Outcomes: As a result of this activity, the reader will be able to: (1) describe current evidence regarding the effects of subconcussive impacts; (2) describe subconcussive impacts on neurocognitive processing and its symptoms; (3) explain the impact of a G-force; and (4) discuss appropriate assessment tools and implementation for long-term concussion management.

In the United States, at least 3.5 million children play soccer yearly and most of them are exposed to mild traumatic brain injury (mTBI) or concussion. A concussion is a traumatic brain injury (TBI) caused by a bump, hit, or jolt to the head or body that puts the brain in motion within the skull.[1] Blows or hits to the head accelerate or decelerate the brain that results in a disruption of the metabolic functioning of the brain, damaging the two types of brain cells: neurons and glia cells. The disruption can result in functional or microstructural damage. Functional damage can be associated with ionic shifts, metabolic changes, impair neurotransmission,

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Concussions: Interdisciplinary Management; Guest Editor, Anthony P. Salvatore, Ph.D., CCC-SLP.

Semin Speech Lang 2019;40:57–64.
DOI: https://doi.org/ 10.1055/s-0038-1676365.
ISSN 0734-0478.

and microstructural damage not readily evident on X-rays or computed tomography (CT) scan. However, recent advances in imaging such as diffuse tensor imaging (DTI)[2] have the capacity to do so. These microstructural and metabolic changes produce some signs and symptoms associated with a concussion. A concussion can affect how one feels physically and emotionally, as well as affecting vision, balance, attention, concentration, sleep, and hunger.

Concussions are a serious injury; nonetheless, soccer players and communities such as parents, interdisciplinary teams, and coaches should be aware of subconcussive injuries since after suffering such an injury the individual can apparently "look normal." Sports-related subconcussive impacts to the head are receiving increased interest.[3] A subconcussive injury is less severe than a concussion. Subconcussion injuries do not usually result in a clinical diagnosis, nor are they commonly identified by neuroimaging studies such as magnetic resonance imaging (MRI), CT scan, or positron emission tomography (PET) scan. Soccer players are at risk of receiving at least one impact during a soccer game.[4]

Heading the ball or the ball contacting the head during a soccer match can produce a subconcussive impact.[5] Heading the soccer ball involves moving the head to redirect the ball in another direction. While heading also puts the brain in motion, it does not tend to reach acceleration thresholds that produce a concussion; nonetheless, it may bring on symptoms. Some injured individuals may notice temporary dysfunction across one or multiple sensory/motor activities, while others may ignore them and/or fail to report them. Repeated subconcussive injuries potentially have long-term consequences in someone who may never have suffered a concussion.

SUBCONCUSSIVE HEAD INJURY IN SOCCER

The primary reasons for heading a soccer ball are to clear the ball, pass it to another player, or capture it and gain control of the ball. According to Shewchenko et al,[6] heading the ball can be divided in three phases: preimpact, ball contact, and follow-through. In the preimpact phase, a player places the feet apart in a split stance, knees are bent, and the torso is tilted forward above the hips in preparation to receive the head impact of the soccer ball. During the ball contact phase, the torso is flexed forward, head and shoulders move at the same time with the torso, and the ball contacts the head. The follow-through phase is a continuous motion of the torso and the head immediately following head contact with the ball, which is then followed by deceleration of the body to regain balance and control of the body.

Heading increases the velocity or speed of the ball. Speed and velocity are terms used interchangeably. Speed is the distance traveled by an object in interval of time and velocity explains the magnitude of displacement and its direction.[7] A kicked soccer ball can reach a maximum speed of around 60 mph (100 km/h). The influence of the speed of the ball making contact with the head and the potential severity of brain displacement have not been investigated. However, we do know that a kicked soccer ball reaches about 45 mph (72.4 km/h); then, after the ball touches the turf and hits the head, it reaches a speed of about 55 mph (88.5 km/h).[8] A soccer ball's mass, size, and internal pressure can also influence its acceleration. All of these suggest that heading the ball is not an inconsequential event in terms of its potential impact on the movement of the brain.

According to Stern et al,[9] heading the ball in soccer usually involves an angular acceleration of the head, before the head impacts the ball. Acceleration is the change of velocity of an object in every second.[7] A rapid and linear acceleration of the head, to impact the ball, results in an injury characterized by a force that moves through the midline of the head. Most of the magnitude of headings are expressed in G-force. An impact of 2 G represents that the object was traveling at two times the constant acceleration ($9.81\ m/s^2$) due to the gravity of the earth. Linear acceleration is usually less damaging than the angular acceleration, which usually causes a more severe trauma. Angular and linear acceleration both cause a compression force within the skull, producing tearing and eventually erosion of brain tissues. Over time, these factors can cause diffuse axonal injury within the brain. Head impact exposure can be calculate for each player by counting the number of impacts and the magnitude (G-force;

maximum peak acceleration of a single impact) of each impact via a head-mounted sensing instrument. Zhang et al[10] have reported that serious brain injuries can be detected at a range of 73 to 133 G.

There are gender, anatomical, and biomechanical differences for head impacts. Females have less head mass and girth. Higher strength in neck (flexor and extensor) can be protective, helping to transfer the energy of the ball in an efficient way.[11] Gutierrez et al[11] argued that practitioners should take into consideration the differences in body composition given that women are predisposed to experiencing greater impacts than men. In addition, these authors[11] presented data on biomechanical tendency in children and women that shows they have lower stiffness in the neck area which increases the possibility of transferring energy to the head when compared to a men. Good muscular strength, especially of the neck muscles, can reduce concussions or mTBI (subconcussive impacts), especially when the player anticipates an impact with the ball or some other player.

Young brains can be more adaptive and protective than an adult brain; however, younger brains are vulnerable to changes in cerebral blood flow and level of myelination.[12] Pediatric, adolescent, and young adults are of interest because the brain continues to develop into the early 20s. The bones of the skull are less dense early in development but increase in density as the individual reaches adulthood.[13] More recent evidence mentions that severity of the impact and age correlate negatively in predicting player recovery.[8] Player position can also make a difference in the prevalence of subimpacts and risk of an mTBI. Maher et al[14] report that 70.2% of the defense players and 78.9% of the goalkeepers have an mTBI in a season, unlike the midfielders and the forwards who reported only 57.7 and 57.4%, respectively. In addition, these data imply that defensive players and the goalkeeper are the most at risk as they are more likely to suffer more mTBI than the strikers and midfielders.

In response to continued issues of practicality and sensitivity, researchers describe sports-related subconcussive impacts in all ages as cranial impacts that do not result in known or diagnosed consciousness.[5,15] Most common signs and symptoms are headache, unbalance, loss of consciousness, neck pain, ringing in the ears, blurry vision, numbness, depression, difficulty in concentrating and remembering, stomach ache, appetite disturbance, irritability, disorientation, confusion, reduction in task attention, drowsiness, difficulty falling asleep or sleeping more than usual, and dizziness.[16,17] Symptoms of higher priority and attention above all are headache, neck pain, concentration difficulty, confusion and sensitivity to light, and dizziness.[13,18]

DIZZINESS ASSESSMENT AND SUBCONCUSSIVE IMPACTS

Headache can be described as head pain, and dizziness can be described as being lightheaded or unbalanced. Dizziness can be classified into four types: vertigo, disequilibrium, presyncope, and lightheadedness.[19] Vertigo can be described as a false sense of motion or spinning sensation. Vertigo includes benign paroxysmal vertigo, vestibular neuritis, labyrinthitis, and Meniere's disease. Disequilibrium is feeling wobbly or feeling unbalanced. Presyncope is the feeling of losing consciousness. It can includes arrhythmias, infarctions, and orthotic hypotension. Lightheadedness can produce a sensation of disconnection with the environment. Common causes of lightheadedness is anxiety, depression, and hyperventilation. Hyperventilation is the breathing in excess of the requirements of the body. Dizziness as a symptom can be useful in the field as an indirect measurement of changes in the homeostasis of the brain after an injury and potentially a discriminatory instrument and useful on the playing field.

One such instrument is the modified version of the Dizziness Handicap Inventory (MDHI) scale,[20] which consists of eight questions. This scale consists of the following questions: (1) Do you feel dizzy when you look up? (2) Do you feel dizzy when you walk on a line or on the ground ? (3) Do you feel dizzy when you lie down or turn around? (4) Do you feel dizzy when you read? (5) Do you feel dizzy when you make fast movements with your head? (5) Do you feel dizzy when you bend the trunk forward? (6) Do you feel dizzy when you bend over? (7) Do you feel dizzy in open places? (8) Do you feel dizzy when you turn around or go to bed? Each question is rated on a scale of 0 through 6 and then the ratings are totaled; 6-5 indicates severe symptoms of dizziness, 4-3 moderate, 2-1 light, and 0 no symptoms present. All athletes should be encouraged to hydrate during a game every 12 minutes to avoid symptoms of dizziness associated with dehydration. Athletes should also be educated about the symptoms associated with dizziness so the athlete may be compliant in reporting symptoms of dizziness during a match.

VULNERABILITY OR RISK FOR FUTURE BRAIN INJURY

There is clearly no single assessment or protocol to identify the symptoms associated with subconcussive impacts and thus vulnerability for a subsequent brain injury. As a clinician, one of the most important issues in sports-related brain injury is how repeated head impacts are affecting the pathophysiology of the brain. For example, immediately following a traumatic insult to the brain, a complex cascade of neurochemical and neurometabolic events occurs.[21] According to Giza and Hovda,[4] ionic shifts can be associated with migraine headaches or sensitivity to light or loud sounds. Metabolic changes can also be associated with vulnerability for a second brain injury. Axonal injuries are associated with impaired signal transmission to networks of cognitive functions, slowed processing time, and slowed reaction times. However, every head injury is different, making it a challenge to predict the true duration of vulnerability[22] for a second head injury, following the initial injury.

CLINICAL ASSESSMENT FOLLOWING SUSPECTED SPORTS-RELATED BRAIN INJURY

Emerging evidence reported in the study of Bailes et al[8] suggests that head impacts that commonly occur during contact or collision sports may not produce outward or visible signs of neurological dysfunction. To date, there is no assessment directly validated for subconcussive impacts. In addition to the ImPACT assessment for adults, the ImPACT Pediatric Neurocognitive test was released for use with children aged 5 to 11 years to describe changes in cognitive functions such as sequential memory, word memory, visual memory, and rapid processing.[23]

A preseason assessment whether accelerometers are going to be used to monitor the frequency and magnitude of head impacts should involve collection of the following information: (1) sociodemographic questionnaire of general information, such as participant's name, age, emergency contact, and social data, and health history, such as allergies, conditions, recreational activities, and others; (2) parents and the participant should attend a talk to explain the use of the accelerometer, what it measures, and its purpose. Finally, the administration of a standardized neurocognitive test that measures attention, memory, and/or cognitive functions should be done.

Communication is supported by the cognitive functions of attention, memory, and executive functions.[9] Attention is defined as a resource that improves or limits performance depending on whether it is applied or removed from a task.[24] Attention can be segmented into components that progressively reflect an increase in the levels of the cognitive workload. Memory can be conceptualized as a series of phases through which the information passes to a permanent storage.[25] Cognitive science has replaced the concept of immediate memory with the concept of working memory (WM), which is a space of limited capacity in which information decays within a few seconds unless it is rehearsed. WM is considered a mental space for storing temporary results of cognitive operations during complex cognitive processing that includes targeted behavior.[13,26] Furthermore, WM is associated with academic achievement, including the development of math skills and literacy skills. The speech-language pathologist is responsible for reporting to the athlete, their significant other, or parents, teachers, and administrators on the implications and precautions regarding linguistic competence (e.g., semantics, syntax, and morphology) and academic competence. Furthermore, studies are needed to understand the true rate of head impacts in soccer players to develop an appreciation of the relationship between subconcussive impacts and executive functions.

ROLE OF ACCELEROMETERS IN PREVENTION AND TREATMENT OF REPETITIVE HEAD IMPACTS

Accelerometers measure the magnitude and number of the subconcussive impacts online during a game. For example, low-to-moderate impact magnitude between 13 and 60 G can cause differences in attention and rapid processing in kids between 9 and 11 years.[2] Long-term cumulative effects in headings of soccer are unknown; however, there is a strong suspicion that repetitive head impacts may be associated with degenerative brain functions.

One example of an accelerometer used for soccer impact monitor is called xPatch, which explored the association between head impact exposure and pre- and postmeasurements.[27] Athletes wear a sensor patch during games. The xPatch is identical to the xGuard (a mouth guard) which was validated by an independent biomechanics laboratory in Stanford University.[28] The xPatch is 1 cm × 2 cm and is mounted with single-use adhesive behind the ear and it contains a triaxle, which measures linear acceleration along three axes.

Another accelerometer that has been validated is the SIM-G (Smart Impact Monitor). The SIM-G is used with an adjustable headband adjusted to the circumference of the player's head. It measures the acceleration of head impacts with the soccer ball. The SIM-G is a small portable device that measures change in velocity during an impact and provides estimates of magnitudes (G) and angles. The SIM-G is 1.04´´ (26.4 mm) A × 1.33´´ (33.78 mm) L body and antenna (tail) 0.285´´ (7.24 mm) A × 3.3´´ (84 mm) L, and is wireless up to 150 yards (137 m) depending on the environmental conditions.

The advantageous feature of using any valid and reliable accelerometer with soccer players is to establish baselines for prevention, guidelines during games, and research. These instruments are affordable and cheaper than imaging studies and blood samples analysis. They are also easy to use during practice and game situations.

Efforts to minimize subconcussive impacts have also led to development of head protection gear (e.g., helmets, protective bands). This strategy has not reduced the potential risk of brain injury. This state of affairs is worrisome given that during the school age, a large number of students begin to participate in sports, such as football, soccer, and basketball.[29] Annually, there are between 4 and 22% reported head injuries related to soccer, and data on blows received to the head by the ball and concussions are inconclusive.[13]

LONG-TERM CONSEQUENCES OF REPEATED SUBCONCUSSIVE HEAD INJURIES

There is concern that in athletes who suffer several concussive and repeated subconcussive impact across their lifetime, the cumulative effect can lead to neurological impairment or neurodegenerative diseases later in their life such as chronic traumatic encephalopathy (CTE). Postmortem studies in rats have identified that repeated subconcussive impacts may have an accumulative effect.[30] CTE is a neurodegenerative tauopathy related to repetitive exposure to mTBI.[31] CTE is associated with atypical symptoms in behavior, mood, cognitive, and/or motor dysfunction. The prevalence of CTE in the population of athletes is unknown. Today, the localized accumulation of tau protein caused by multiple long-term impacts is attributed to repetitive brain trauma, causing CTE in long term.[9] Rabinowitz et al[32] argued that, in order to have an estimate of the prevalence of CTE, they must rely on the series of autopsies of confirmed cases. Studies based on a population of living individuals with CTE are not possible due to the lack of consensus on clinical diagnostic criteria for CTE. Presently, the diagnosis is only possible at autopsy.

At present, the pathophysiology of subconcussive impacts is not completely understood. According to Echemendia,[33] the pathophysiological process induced by a biomechanical force can affect the brain's processing of information. Though mTBI and concussion affect individuals at all stages of life, there are age groups that have a higher risk of trauma to the brain. For example, pediatrics, adolescents, and adults may participate in contact sports such as soccer, basketball, and football in a variety of contexts. The brain in children, adolescents, and young adults continues to develop and therefore is susceptible to diffuse brain injury more so than a mature brain. Furthermore, Echemendia[33] and Harmon et al[34] reported that children and young adults show a slower recovery from concussion.

RESEARCH EXAMPLE

To address the research needs reviewed here, we designed a prospective cohort study to describe the outcomes and changes in the neurocognitive functions and the magnitude of one or more subconcussive impacts during a soccer game in a three-weekend tournament league for children from ages 9 to 11 years.[2] A group of 30 participants was assessed prior to and following a series of two or three soccer matches. A total of 42 header-impacts were recorded in 23 of the 32 participants. The range of acceleration (G-force) for male players was 16 to 60 G, with a mean of 23.8 G and a standard deviation of $\pm$ 9.1 G. The range of acceleration (G-force) for female was from 15 to 21 G, with a mean of 17.5 G and a standard deviation of $\pm$ 5.1 G. During the matches, no participant reported symptoms consistent with a concussion.

Each participant that headed the ball at least one time during the game was asked to complete the ImPACT Pediatric Post-test. This neurocognitive test assesses cognitive changes in the areas of sequential memory, word memory, visual memory, and rapid processing. The pretest was given 1 week before the series of games and the posttest 10 minutes after each game.

The results showed that the players experienced three to eight header-impacts per game, especially among the male players. The resulting average header angle was <25 degrees for females and <35 degrees for male. Neurocognitive test means $\pm$ standard deviations pre- and postmatch were: sequential memory, 50.8 $\pm$ 8.5 and 41.4 $\pm$ 14.1; working memory, 49.3 $\pm$ 5.7 and 49.7 $\pm$ 6.6; visual memory, 50.2 $\pm$ 7.6 and 52.7 $\pm$ 7.1; and rapid processing, 59.2 $\pm$ 7.5 and 59.8 $\pm$ 6.5 (see Table 1). Paired *t*-tests for sequential memory, working memory, visual memory, and rapid processing (pre- and posttest) were not significant ($p > 0.05$). Participants in both genders showed changes in sequential memory after at least one subconcussive impact.

Evidence indicates that at least 75% of youth soccer players aged 9 to 11 years are exposed to receive at least one impact during a soccer game. Male and female participants showed changes in sequential memory after at least one subconcussive impact. Sequential memory dysfunction is associated with impairments in word recognition, oral reading, and reading comprehension. Male participants evidenced changes in rapid processing. Rapid processing dysfunction could affect areas such as auditory processing and language skills.

Head-ball impact magnitude showed a range of 16 to 60 G. Participants received most of the impacts in the frontal (>50%) and occipital area (>30%) of the skull, where the brain areas responsible of cognitive functions and language are located.[13] A subconcussive impact to the head of 15 G-force or more could present neurocognitive challenges in sequential memory and rapid processing.[2]

IMPLICATIONS

In Puerto Rico, where the study was conducted, an interdisciplinary team of health professionals identified a need for standardized treatment and evaluation protocols. Future research should also examine further the link between subconcussive impacts and potential long-term health complications. We suggest the initiation of a longitudinal research study designed to examine groups of soccer players across a series of age groups since the present study showed a relationship between the magnitude of head-ball impact per game and diminished neurocognitive functions in specific cognitive functions.

Powell and Salvatore[35] reported on a program they helped establish in El Paso Parks and

Table 1 Mean and SD Values of Pre- and Posttest for both Genders

ImPACT Pediatric	Pretest mean $\pm$ SD	Posttest mean $\pm$ SD	Paired *t*-test
Sequential memory	50.8 $\pm$ 8.5	41.4 $\pm$ 14.1	$p = 0.04$
Word memory	49.3 $\pm$ 5.7	49.7 $\pm$ 6.6	$p = 0.27$
Visual memory	50.2 $\pm$ 7.6	52.7 $\pm$ 7.1	$p = 0.14$
Rapid processing	59.2 $\pm$ 7.5	59.8 $\pm$ 6.5	$p = 0.87$

Recreation Department programs to protect children ages 5 to 12 years from a concussion risk or mTBI. The rule changes implemented included not hitting the soccer ball with their heads until they reach the age of 12 years. During the development of the brain, any injury to the brain may produce reorganization of neural functions and thus adversely affect an athlete's long-term educational, employment, social, and emotional development.

Based on the experience of the first author in carrying out the study above, speech-language pathologists should work "hand in hand" with an interdisciplinary team to educate players, coaches, officials, school administrators, athletic trainers, and parents about concussion. Special attention should be afforded to individuals who have incurred more than one subconcussive impacts or an impact greater than >50 G.

PREVENTION RECOMMENDATION FOR SOCCER PLAYERS

A soccer player should not engaged in heading the soccer ball until the age of 12 years. Until then, young players can learn the skill of heading with a nerf ball.

FINANCIAL INTEREST

We do not have financial relationships relevant to the content of the paper.

DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this paper.

ACKNOWLEDGEMENT

Special thanks to Luis R. López-Román, MExSc CSCS, who supported research in the areas of methodology and analysis results, and reviewed manuscript details of pathophysiological areas.

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