Journal of Biosensors & Bioelectronics
ISSN: 2155-6210

Morrison et al., J Biosens Bioelectron 2015, 6:4
DOI: 10.4172/2155-6210.1000189

Research Article Open Access

A Biosensing Approach for Detecting and Managing Head Injuries in American Football

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Abstract

We describe our real-time biosensing approach to detecting and managing head impacts in football at the University of Mississippi as well as Heads in the Game, our high school outreach program. Our work is in response to the fact that sports are the second leading cause of traumatic brain injury for people aged between 15 and 24 years [1,2]. Additionally, the Center for Disease Control estimates indicate that 5,000 concussions occur at the high-school level for every concussion in the NFL, and that 3.8 million sports brain injuries occur annually. Mild Traumatic Brain Injures (mTBI) are often not reported in high school football due to injury underestimation, motivation to remain in play, and lack of awareness. Resources and education for improved athlete concussion management reduces the player's susceptibility to cumulative or catastrophic brain injuries [3]. Our system uses X2 Biosystem's xPatch 6DOF mounted directly behind the player's ear and features a secure wireless telemetry system for reporting head impacts in real time to an analysis system that is capable of reporting the major characteristics of the impact in near real time. Collected data will also contribute to understanding the potential long-term effects of brain injuries such as second impact syndrome (SIS) [4]. Pilot studies with the University of Mississippi football team show significant reduction of head impacts through improved form and education, by reducing the overall head impact, improving impact distribution, and reducing dangerous impacts, mechanisms for improving remove-from-play (RFP) and return-to-play (RTP) decisions, assessing impact severity, coaching and training, and understanding the pathology of mTBI and long-term brain injuries causing persistent cognitive impairment. We discuss research partnerships as well as the Heads in the Game program, a high school concussion research program with University of Mississippi Athletics.

Keywords: Mild traumatic brain injury; Second impact syndrome; Telemetry system

Introduction

Our objective is to contribute to the development of an evolving platform for research, development, and application of state-of-the art devices and practices for the prevention, detection, and management of head injuries across the board. A comprehensive platform using X2 Biosystems xPatch device, which measures linear and rotational acceleration about all axes and utilizes impact detection algorithms to determine the characteristics of an impact, and a telemetry system providing secure and reliable transmission of impact data to athletic trainers and coaches in real time, will permit informed and easy-to-use data for coaches and trainers at all levels to mitigate head impacts. We used head impact profiles in this pilot study to provide a proactive and prescriptive approach to reducing head impacts to athletes through education and improved hitting form, providing a healthier environment for participation in athletics.

We turn to a review of some basic facts that motivate our work. According to the 2000 US. Census, 50 million youth were involved in organized sports [1-5]. Approximately 57% of high school students participated in at least one sport [6], and that participation in sport participation increased by over 350% between 1990 and 2008. Female athletic participation has increased from 294,000 in 1971 to 3.1 million in 2009 [7]. Sports contribute to promotion of virtues through teamwork, respect, and dedication [8], reduction of the risk of type 2 diabetes, improvement of metabolic and musculoskeletal health, reduction of the risk of obesity, and increased probability of improved health in adulthood [9]. Sports with high rates of concussion include football, soccer, lacrosse, and hockey.

The increase in youth sports, as well as the growing popularity of collegiate and professional sports, has led to growing concerns about concussions and mild traumatic brain injuries (mTBI) suffered during play. In 2006, middle school football player Zack Lystedt returned to a game after enduring a concussion and reporting head pain. Zack suffered a life threatening brain injury due to playing with symptoms from a concussion, which resulted in diffuse cerebral swelling, brain herniation, coma, and permanent brain damage.

Return-to-play (RTP) protocols have been implemented throughout the country as the result of the Lystedt Law, which was passed in the state of Washington in 2009 and mandates concussion education for young athletes and parents, immediate removal of an athlete suspected of a concussion, and implementation of RTP protocols. The National Collegiate Athletic Association (NCAA) and the National Football League (NFL) have implemented RTP protocols for athletes who sustain head impacts during the course of the game. All 50 states have passed new laws that require young athletes to be examined by a trained medical professional before they are cleared to returning to play.

Concussion education and management tools are increasingly used to reduce an athlete's susceptibility to cumulative or catastrophic

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Received November 06, 2015; **Accepted** November 16, 2015; **Published** November 26, 2015

Citation: Morrison M, Daigle JN, Ralston J (2015) A Biosensing Approach for Detecting and Managing Head Injuries in American Football. J Biosens Bioelectron 6: 189. doi:10.4172/2155-6210.1000189

brain injuries. Second Impact Syndrome [4] is a rare but often fatal traumatic brain injury. The pathology of SIS is poorly understood, but CT scans of SIS patients show that loss of regulation of cerebral blood flow results in massive hyperemia [10-18]. Virtually all reported cases of SIS occurred in adolescents [19].

Sports participation has dropped at the high school level by 4% since 2009, and many parents have cited concussion fears as their main concern. Many parents are forced to decide between the benefits of allowing their children to participate in sports and the risks of head impact. Mechanisms for understanding head impact severity, improving coaching and training of players, and understanding the causes of mTBI that lead to persistent cognitive impairment may reduce public fears and ultimately make sports safer for student athletes.

Many of the health challenges addressing student athletes face the general population of the state of Mississippi, which ranks 50th in overall health according to the United Health Foundation. Mississippi faces serious challenges in fighting poverty, engendering health, and promoting education [12]. The state's poverty rate rose to 22.5% in 2013, despite the national average dropping to 14.5 percent. Access to education is a factor in overall well-being; 62% of Mississippi residents with a college education are listed as having "very good" health, but that rate drops to only 24.2% when considering residents without a high school diploma. Mississippi graduated only 62% of high school students in 2009, the second worst in the nation and well below the national average of 75.5 percent. The impact of the recent decrease in sports participation would only exacerbate these existing health problems in Mississippi. Therefore, any program that improves access to health and education and allows students to grow academically through sports will be of great benefit to the state of Mississippi.

The Heads in the Game program is a STEM outreach program for high school students whose aim is to increase the understanding of the causes and management of concussions. Sixteen high school students spent one month on the campus of the University of Mississippi to conduct research with Athletics and Electrical Engineering. They learned about multidisciplinary approaches to biosensing head impacts and to create a database to determine what factors, if any, cause student athletes additional susceptibility to SIS. Students learned about computer programming and engineering, neurology, biomedical sciences, and sports and health performance.

Overview of principle system components

The X2 Biosystems Injury Management System utilizes the xPatch biosensor and the Integrated Concussion Evaluation (ICE) software to aid in monitoring head impacts. The xPatch contains a microelectromechanical system (MEMS) consisting of a gyroscope and an accelerometer. The device measures linear acceleration and rotational acceleration about each axis in order to accurately measure head impact kinematics. The MEMS chip provides low-power, highly accurate measurements collected by a microcontroller device. The devices have 20 capacitive sensing channels supporting touchkey, linear and rotary touch sensors, can sustain upwards of 10000g in an impact without being damaged, and can operate between -40°C and 105°C. The sampling rate of the xPatch is 1ms and it takes 100 samples once the device's sleep-to-wakeup function is activated after an impact. The device also contains a transceiver which can transmit data in allocated Industrial, Scientific and Medical (ISM) radio bands of 150-174 MHz, 300-348 MHz, 387-470 MHz, and 779-956 MHz.

Many collegiate and professional stadiums have wireless networks, which are in the 2.4 GHz band or 5 GHz band for paying customers. Providing communication in different bands provides an additional layer of security in order to provide HIPPA and FERPA anonymity for each student athlete. The device provides an air data rate of 100 Kb/s. Additionally, the xPatch device uses impact detection algorithms in order to identify and discard spurious triggers.

Software and SCAT3 compliance

The X2 Integrated Concussion Examination (ICE) system is a Microsoft Azure HIPAA-compliant cloud-based storage and processing center that provides real-time baseline information of a student-athlete to athletic trainers, trained medical personnel, and authorized coaches and players [15]. ICE combines athlete concussion history, pre-season neurocognitive function, balance, and coordinate-performance data to create a baseline for comparison after a suspected injury event. The cloud-based system permits access via authorized mobile devices from anywhere in the world.

ICE meets the Sport Concussion Assessment Tool 3 ("SCAT3") standards used by the NCAA for determining RTP eligibility [16,17]. The ICE graphical user interface permits baselines assessments, which document previous concussions, learning disabilities, ability to recall a set of words and numbers, and medications. ICE's baseline tool uses cognitive assessment that tests an athlete's orientation, immediate memory, concentration, neck movement, symptom evaluation when no impact has occurred, balance examination, coordination examination, and delayed recall ability.

Additionally, ICE permits sideline assessments that provide indications for emergency management. The athletic trainer can document an athlete's loss of consciousness, balance or motor incoordination, disorientation, loss of memory, and visible facial injuries (Figure 1).

Mississippi football pilot program

During spring practices in 2015, 10 student athletes on the University of Mississippi Football team wore xPatch devices in order to monitor head impacts. After each practice, players reviewed their head impact profiles in order to determine their head impacts relative to hitting and tackling technique. X2 Biosystems utilizes a proprietary score called xSposure in order to relate acceleration measurements with

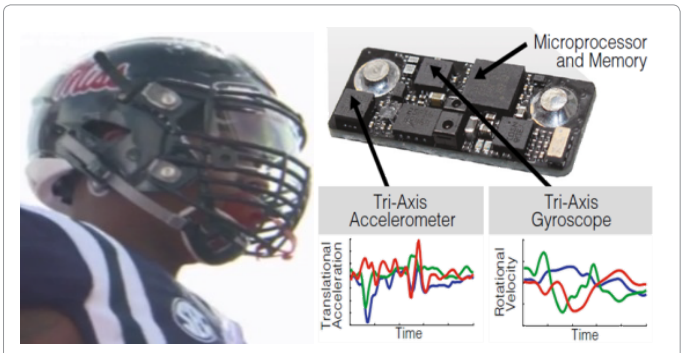

Figure 1: (left) Photograph of a University of Mississippi student-athlete wearing an xPatch device behind the ear under the helmet during a game. (right) Biosensor design and output waveforms. Each sensor measures linear and rotational acceleration about each axis and collects 1 sample each millisecond for 100 milliseconds after the MEMS wake-up function is activated. Each waveform contains the acceleration about x, y and z, and the maximum instantaneous acceleration.

impact duration with probable impacts. Each impact is scored from 1 to 10. The device also calculates scores of Gadd severity index (GSI), the head impact telemetry severity profile (HITsp), and the generalized acceleration model for brain injury threshold (GAMBIT).

Impacts on top of head, the source of the majority of NFL and NCAA concussions [18,20], cause rotations about the z-axis since the force is forward of the center of the neck. These impacts cause the greatest strain at the midbrain. Concussions relate to head and neck movement, so reducing impacts forward of the center of the neck allows the neck to maintain strength, ultimately reducing the acceleration of each impact and the probability of a concussion. Additionally, since the facemask rests significantly in front of the face, impacts directly to the facemask create a greater moment arm to create rotational acceleration about the z-axis, causing strain on the midbrain. A hit to the front of a facemask has an effect similar to that of an uppercut, which results in a significant number of knockouts in boxing matches.

On average, players reduced their per-hit xSposure score by 15% from the first practice to the Spring game. A comparison of a student-athlete's impact profile is shown in Figure 2. On the first day of practice, the player led with the top of his head significantly more than the rest of his head. The player, a linebacker, was shown his impact profile and was taught to get his head over to the side when making tackles. His final impact profile is shown on the right, with a reduction of 41% in per-impact xSposure score. Instead, the majority of impacts have reduced acceleration and are almost exclusively on the right side of his head since he was making most of the tackling impact with his right shoulder instead of his head. Taking the tackle's impact with his right shoulder both reduced his head impact and resulted in an increased contact-to-successful-tackle ratio. Additionally, the player reduced the impacts on the front of his face, decreasing their rotational impacts on the z-axis, and the strain on the player's midbrain was reduced.

Telemetry system

One of the challenges of implementing biosensing approaches to head impact detection and management is availability of resources. For example, only 8 high schools have access to certified athletic trainers, and they were hired through school districts, and over 250 high schools in Mississippi do not have access to qualified athletic trainers. Teams with over 50 players and even one athletic trainer will have a difficult time affixing xPatch devices to all the players, keeping track of devices, and then uploading and analyzing data from the xPatch devices after practice. Therefore, teams in school districts with scant resources need a quick and efficient method to collect and analyze impact data.

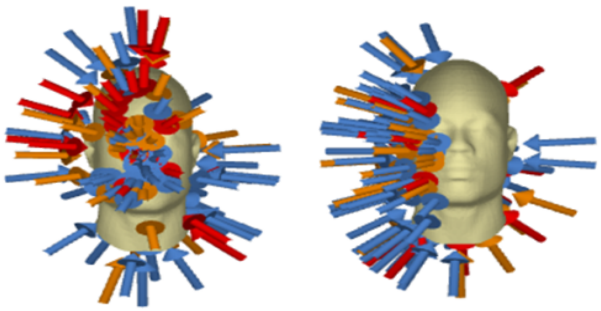

Figure 2: Comparison of hit impact profile improvement in a student athlete. (left) Photograph of a University of Mississippi student athlete wearing an xPatch at the first Spring practice. (right) Improved hitting form in Spring Game.

Figure 3: The Heads in the Game Scholars work on the design of their portion of the Sports Performance Application.

The next stage of this project is installation and test of a wireless access network in Vaught Hemingway Stadium that will securely and reliably collect impacts detected by the xPatch in real time and relay them to the on-site athletic trainers. The University of Mississippi will be outfitted specifically for secure, real-time wireless transmission of in-game athlete collision data to athletic trainers. The wireless transmitter integrated within the xPatch device will transmit data to eight receivers distributed within the stadium for reception of telemetered impact data. The long-term goal is to make the network secure, reliable, and efficient so it may be deployable at high schools and recreation facilities with scant resources.

The xPatch devices will transmit in the 915 MHz ISM Band network, which allows for 10 independent channels of communication. By allocating 100 Kb/s for each device, both football teams could have every scholarship player wearing a device (85 players maximum permitted by the NCAA) transmitting data simultaneously within only two of the channels. The remaining channels may be used for uninterrupted sideline communications between coaches and authorized players on the field, such as the quarterbacks and middle linebackers. Vaught-Hemingway Stadium at the University of Mississippi is outfitted with 800 2.4 GHz ISM access points for use by fans, so using the 915 MHz band will partition consumer and athlete data transmission. The devices will implement the Advanced Encryption Standard (AES), which utilizes the Rijndael algorithm [19-21] to protect student data and keep HIPPA and FERPA compliant. There are currently no known practical security attacks against AES encryption with the correct key length and number of rounds (Figure 3).

Installing eight ISM access points receiving in the 915 MHz band within the stadium permits constant streaming of data in situations where players in close proximity may cause data interference. The transceivers utilize carrier sensing multiple access with collision avoidance (CSMA-CA). Implementation of the xPatch devices as a wireless mesh network provides high-bandwidth coverage over a specific area, such as a football field. When players are in close proximity, such as along the offensive and defensive line or when the players are recovering a fumble in a pile, the devices may act as nodes which reliably relay data to other nodes close to the wireless access points, which makes the impact data accessible by doctors, trainers, and coaches in real time, and the base stations may upload the data to the cloud in real time.

Heads in the game concussion education

The Heads in the Game program [22] is a summer research camp for improving the academic, athletic, and the physical and mental well-being of student athletes at University of Mississippi. The summer

program received 88 applications in one month from high school students in Mississippi, Louisiana, Arkansas, Alabama, Tennessee, Kansas, and Illinois. Sixteen students were selected, and they attended the Heads in the Game program from June 28-July 28, 2015. The students received training in neuroscience and biomedical engineering, site design and wireless communications, and nutrition and sports performance. In the neuroscience and biomedical engineering seminar, students studied concussion protocols, fundamentals of neuroscience, implementation of biomedical engineering devices, such as NeuroCom balance assessment and BODPods, performed altered reality experiments, fundamentals of the nervous and skeletal systems. Students were also trained to properly use the xPatch and ICE software. While students may not make RTP decisions, they are allowed by law to collect baseline data. Three of the scholars are assisting their high schools this fall with baseline assessments. By integrating STEM education with concussion education, students may actively contribute to improving the health and well-being of their classmates in their communities.

The Heads in the Game scholars also completed 40 hours of high school level research-methods work with University of Mississippi Athletics to contribute towards the development of a mobile phone application with which students will be able to track their nutrition, health, and academics. Portions of the application include collecting University of Mississippi student-athlete information into a single database, which permits an infrastructure to determine which additional cultural factors contribute to increased susceptibility to concussions and mTBI. The scholars interviewed athletic trainers in multiple departments with University of Mississippi Athletics, incorporated their feedback into a design layout, and then began the design process. Portions of the application include database design and an injury alert system for providing an avenue for relaying information from doctors and trainers to affected individuals. Additionally since studies show student-athletes who miss more than two weeks of playing time resulting from a concussion have a significant drop in GPA [23,24], students designed an interface within the app to access the University of Mississippi academic websites—such as Blackboard—to provide tutors and students with assistance in the event they have a concussion.

Heads in the Game scholars also implemented secure messaging between departments, time management, interfacing with the X2 Cloud, and athlete wellness. This project is being completed by an electrical engineering senior project team, and will permit student-athletes to enter basic information, such as the solid food and liquids they consume. Athletic trainers will enter information such as their exercise regimen, medications, injury records, and drug testing.

Conclusion

The University of Mississippi has augmented its efforts to provide a healthy environment for its student athletes through the deployment of a system of measurement and analysis of head impact data. As expertise is developed through the collection and analysis of real time data, we anticipate greater cooperation among all departments of the University in which our student athletes are engaged, including academic, health, and administration in addition to athletics. The intended outcomes are both continuing improvement in our ability to manage the health of our student athletes and improved communication and health education for the young people in our state through outreach programs to our secondary schools.

Acknowledgements

This work was supported by X2 Biosystems through the Heads in the Game Research Program and the National Science Foundation through the Broadband Wireless Access and Applications Center (BWAC) I/UCRC. The authors would like to thank the University of Mississippi Athletics, especially all the athletic trainers, for their research partnership, their time, and their valuable feedback to the students. We would like to acknowledge the 2015 Heads in the Game Scholars for their hard work and dedication during the research program. We would also like to thank Dr. Stanley Herring and Dr. Scott Grafton for their valuable feedback, which helped improve this manuscript.

References

1. Thurman DJ, Branche CM, Sniezek JE (1998) The epidemiology of sports-related traumatic brain injuries in the United States: recent developments. J Head Trauma Rehabil 13: 1-8.
2. Sosin DM, Sniezek JE, Thurman DJ (1996) Incidence of mild and moderate brain injury in the United States, 1991. Brain Inj 10: 47-54.
3. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K (2004) Unreported concussion in high school football players: Implications for prevention. Clin J Sport Med 14: 13-17.
4. Saunders RL, Harbaugh RE (1984) The second impact in catastrophic contact-sports head trauma. JAMA 252: 538-539.
5. U.S. Census 2000.
6. Grunbaum JA, Kann L, Kinchen S, Flint KH, Hawkins J, et al. (2004) Youth risk behavior surveillance. United States, MMWR 53(SS-2): 1-95.
7. Sabo D, Veliz P (2008) Go Out and Play: Youth Sports in America. East Meadow, NY: Women's Sports Foundation.
8. True Sport: What We Stand to Lose in Our Obession to Win. U.S. Anti-Doping Agency.
9. Centers for Disease Control and Prevention (CDC) (2008) Prevalence of self-reported physically active adults--United States, 2007. MMWR Morb Mortal Wkly Rep 57: 1297-1300.
10. The Lystedt Law: A Concussion Survivor's Journey, (2010) Center for Disease Control.
11. Ralston J (2014) Introduction to Second Impact Syndrome, X2 Biosystems.
12. America's Health Ranking, Mississippi (2015) United Health Foundation.
13. Ralston J (2014) Introduction to xPatch Device, X2 Biosystems.
14. Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD (2007) Concussions among United States high school and collegiate athletes. J Athl Train 42: 495-503.
15. Ralston J (2014) Introduction to X2 Biosystems Integrated Concussion Evaluation Software (ICE), X2 Biosystems.
16. Maddocks DL, Dicker GD, Saling MM (1995) The assessment of orientation following concussion in athletes. Clin J Sport Med 5: 32-35.
17. McCrory P (2008) Consensus Statement on Concussion in Sport – the 3rd International Conference on Concussion in Sport. British Journal of Sports Medicine 43: 76-89.
18. Viano DC, Casson IR, Pellman EJ (2007) Concussion in professional football: Biomechanics of the struck player--part 14. Neurosurgery 61: 313-327.
19. Daemen J, Rijmen V (1998) AES Proposal: Rijndael National Institute of Standards and Technology.
20. Weinstein E, Turner M, Kuzma BB, Feuer H (2013) Second impact syndrome in football: New imaging and insights into a rare and devastating condition. J Neurosurg Pediatr 11: 331-334.
21. Pellman EJ, Viano DC; National Football League's Committee on Mild Traumatic Brain Injury (2006) Concussion in professional football: Summary of the research conducted by the National Football League's Committee on Mild Traumatic Brain Injury. Neurosurg Focus 21: E12.
22. Morrison M (2015) Heads in the Game Program.
23. Stringer G (2014) Effects of Sport Related Concussion on Academic Performance in High School Athletes. Dissertation, Drexel University.
24. Hawkins A, Grob C (2014) Traumatic Brain Injury. Federal Law Enforcement Training Center, Charleston, SC.