IMPACT FREQUENCY VALIDATION OF HEAD IMPACT SENSOR TECHNOLOGY FOR USE IN SPORT

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Head impact frequency has been identified as a contributing factor to long-term trauma experienced by the brain. A peak linear acceleration greater than 20g has been proposed as defining a single impact. The purpose of this study was to examine the accuracy of a single head impact sensor to identify 20g impacts under short (<7ms), intermediate (15ms), and long duration events (40ms) representative of falls onto hard surfaces, helmet to helmet collisions, and soccer ball to head. A Triax Smart Impact Monitor was outfitted on a Hybrid III headform. The headform was also instrumented with 9 accelerometers to record head acceleration. The headform and the head sensor were simultaneously impacted and corresponding outputs were compared. The head impact sensor was able to detect all short (5ms) and long duration impacts (40ms), however, for 15ms impacts, the sensor reported false negatives for 2 sites.

KEY WORDS: Impact frequency, Headform, Head impact sensor, Reliability, Validation

INTRODUCTION: While some impacts result in immediate effects, a sub-set of sub-concussive impacts, not presenting with clinical signs and symptoms have been identified as potentially detrimental when accumulated over the life span of an athlete (Bailes et al., 2013). Research on animals have demonstrated repeated low-level trauma affects normal functioning of brain tissue at the cellular level and over time can compromise cognition (Kanayama et al., 1996). Cumulative low-level trauma in a combination with a history of concussion are considered risk factors for individuals suffering from long-term neurological diseases such as chronic traumatic encephalopathy (Gavett et al., 2011; McKee et al., 2009). In efforts to manage the potential negative long-term effects of repeated impacts sustained during sport, a number of head impact sensor technologies have been developed to assist coaches and parents in monitoring the amount of brain trauma, in terms of frequency and magnitude of impacts, sustained by athletes (Crisco et al., 2010; Oeur et al., 2014).

Information obtained from head impact sensor technologies can provide a measure of the amount of brain trauma athletes sustain over the course of a game or season of play, and can help make informed decisions about managing playing time and rest. In order to be effective, head impact sensors need to be tested using scientifically rigorous test protocols to ensure that they provide accurate information and report reliable information from one impact to the next. The purpose of this study was to evaluate the capacity of a single head impact sensor to count the number of impacts (frequency) to the head under short, intermediate, and long duration acceleration pulses representative of an impact with a hard surface, such as the ground, a helmeted head impact, and heading a soccer ball, respectively. The validity of head impact sensors to accurately capture the magnitude of impacts is presented in a separate paper (Karton et al., publication in progress).

METHODS: The Triax Smart Impact Monitor, SIM-G model (Connecticut, USA) was used in conjunction with a headband attachment (Figure 1). The SIM-G is a waterproof device (27mm x 34mm x 8mm with a 85mm antenna) weighing 11.5 grams and houses a tri-axial linear accelerometer, tri-axial gyroscope, 900 MHz radio, and lithium battery. Linear acceleration and angular velocity data are sampled at 1kHz and filtered using a 780 Hz and a 250 Hz low-pass filter, respectively. Impact data from the sensor are collected and transmitted to a USB access point attached to a desktop computer allowing real-time display of head impact data. The Triax sensor has the ability to store impacts on the device if real-time connection with the desktop computer failed at any point during the testing. Only the sensors linear acceleration signals were compared with headform results.

The sensor and headband were mounted on a Hybrid III headform according to the manufacturer's specifications. The Hybrid III headform was instrumented with 9 accelerometers capturing data at 20 KHz, however only 3 accelerometers at the centre of gravity of the headform, measuring x, y, and z components were used to record linear acceleration of the head at impact. These component accelerations were resolved to determine the resultant linear acceleration, which were used to compare with results from the head impact sensor.

Figure 1 Triax Smart Impact Monitor and headband attachment

A test protocol defining centric and non-centric impacts under representative helmeted and un-helmeted conditions in sport were used to evaluate the reliability of the sensor (Oeur et al., 2014). A head-to-ground, or fall impact is represented by a short duration acceleration pulse lasting less than 7ms. An intermediate acceleration pulse lasting approximately 15ms, represents a helmet-to-helmet impact (Hodgson & Thomas, 1972). A ball-to-head impact representing heading a soccer ball was characterized by a 40ms duration event (Oeur et al., 2014). The head-to-ground and head-to-ball impacts were performed on a monorail drop system with an un-helmeted Hybrid III headform onto a steel and soccer ball anvil, respectively. Impact sites selected for these conditions were a front and side impact location to cover motion in the primary directions common to falling and heading the ball in soccer. The helmet-to-helmet impacts were performed using a pendulum system with a nylon-capped vinyl nitrile striker (Figure 2). The impact sites used for this condition were adopted from Walsh et al. (2011) and Post et al. (2014) to represent a series of centric and non-centric impacts that create risk of concussion in helmeted sports.

The goal of this protocol was to test the ability of a head impact sensor to count the number of impacts above a peak resultant linear acceleration of 20g. A 20g head linear acceleration has been proposed as the minimal criteria with which to measure Hit Count® frequency (Cantu et al., 2014) because it is associated with a low risk of concussion (typically around 60g; (Zhang et al., 2004)) however is considered to be a level associated with abnormal head accelerations not commonly seen in running and jumping (10-15g; Allen et al. (1994)) The headform and the head impact sensor were simultaneously impacted under all conditions and the corresponding outputs were compared. An impact detected by the sensor at a headform acceleration of 20g was noted as a 'hit' and those not detected by the sensor but identified by the headform as 20g, were noted as a 'miss'. All 'hits' and 'misses' were tallied.

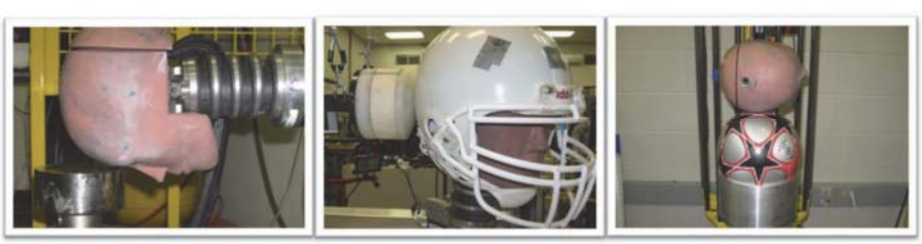

Figure 2 Test set-up for head-to-ground (7ms), helmet-to-helmet (15ms), and ball-to-head (40ms) events.

RESULTS: Impact results for the head impact sensor are shown in Table 1 for head-to-ground, helmet-to-helmet, and head-to-ball conditions. All impacts were detected except for the Front Boss Positive Azimuth and Side Centre Gravity for the helmet-to-helmet conditions, which are impacts directed in the sagittal plane.

Table 1
Impact Frequency Results for the Head Impact Sensor

Impact Condition	Impact Site	Triax Smart Impact Monitor
Head to Ground (7ms)	Front	3/3
	Side	3/3
	Subtotal	**6/6**
Helmet-to-Helmet (15ms)	Front PE	3/3
	Front Boss CG	3/3
	Front Boss PA	0/3
	Side CG	0/3
	Rear Boss NA	3/3
	Rear NA	3/3
	Rear CG	3/3
	Crown	3/3
	Front FG	3/3
	Subtotal	**24/30**
Head-to-Ball (40ms)	Front	3/3
	Side	3/3
	Subtotal	**6/6**

DISCUSSION: This study presents a comparison of results from a head impact sensor with those from an instrumented headform subject to an impact protocol representative of different types of hits common to sport. While reliability and accuracy of the sensor are important, the reliability of the sensor to detect head impacts occurring at 20g was the purpose of this study. The accuracy of head impact sensors in capturing peak acceleration is presented elsewhere in this conference proceeding (Karton et al., publication in progress).

The head impact sensor tested in this research accurately counted all impacts for short (7ms) and long duration (40ms) events, representative of impacts with hard surfaces such as the ground, and soft surfaces like soccer balls. While the head sensor was able to capture most helmet-to-helmet impacts, it tends to be less accurate for the Side CG and Front Boss PA sites. These two sites are directed at the side of the headform, driving the motion of the head in the sagittal plane, where one occurs through the center of gravity and the other is outside. Reconstruction research examining concussive impacts in contact sports, such as rugby and Australian Rules football, have identified impacts to the side to be associated with the highest incidence of concussion (McIntosh et al., 2000, 2014; Patton et al., 2013). This is consistent with previous experimental animal research identifying medial-lateral loading of the head of primates to have a decreased tolerance to concussive outcomes (Hodgson et al., 1972). While impacts at larger magnitudes than 20g may be captured by the sensor for these directions, low-level loads would less likely be recorded, and therefore the overall frequency of loading to the head may be underreported. This may have negative consequences when using head impact sensor technologies for managing head trauma exposure and injury risk for athletes in contact sports.

Evaluation of head impact sensors using a multi-condition impact protocol highlights the benefits and limitations of using these technologies to monitor trauma load to the head. Despite having a low rate of false negatives (6/30), the sensor evaluated in this study reported consistent consecutive readings for the same sites and conditions, demonstrating the reliability of the Triax sensor software and build for centric and non-centric dynamic loading. Additionally, the high rate of impact detection for all other conditions demonstrates the reliability of the sensor, providing some piece of mind when used in practice. This study demonstrates the continued need for rigorous test protocols to evaluate head impact sensors in order to understand the information obtained from these technologies and how impact data should be interpreted in light of their limitations. This can contribute to a better understanding of their capacity to capture head trauma loads in sport which can aid coaches, parents, and physicians in making important decisions regarding management of brain health.

CONCLUSION: Head impacts in sport are complex and varied, involving short, intermediate and long duration acceleration pulses. This research evaluated the reliability of a head impact sensor technology to count the frequency of 20g impacts to the headform. The head impact sensor was able to detect all short and long duration conditions including 24/30 impacts for helmet-to-helmet condition, 6 impacts were identified as false negatives. The complex nature of impacts in sport requires the continued need for manufacturers to ensure that they provide accurate and reliable data for protecting athlete's participation in sport. This research describes the trauma information provided by impact sensors and limitations of impact monitoring technologies for use in sport.

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