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Short communication

Collegiate women's soccer players suffer greater cumulative head impacts than their high school counterparts

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ABSTRACT

Soccer is the source of the highest concussion rates among female athletes and is associated with neurological deficits at many levels of play. Despite its importance to our understanding of head trauma in female athletes, little is known about the number and magnitude of head impacts experienced by female soccer players. Head impacts experienced by high school and collegiate athletes were quantified using xPatch sensors (X2 Biosystems) affixed behind the right ear of each player.

The average peak translational acceleration (PTA) sustained by players at the high school level was significantly lower than that of the collegiate players, but the average peak angular accelerations (PAA) were not significantly different. Given that the collegiate players took many more impacts throughout the season, their mean cumulative exposure to translational (cPTA) and angular accelerations (cPAA) were significantly higher than those of the high school players. Additional research is required to determine whether the differences in cumulative exposure are responsible for the elevated risk of concussion in collegiate soccer players or if there are additional risk factors.

1. Introduction

The potential for chronic brain damage resulting from repetitive head trauma is a serious concern for athletes participating in collision sports (Bailes et al., 2013). While head injuries in American football dominate the public's attention, soccer is responsible for the largest number of head impacts and highest concussion rates among female athletes (Covassin et al., 2003a, 2003b; Gessel et al., 2007). More importantly, studies looking at all levels of soccer play have shown that participation in soccer is associated with neurological deficits, even in the absence of a head injury diagnosis (Matser et al., 1999; O'Kane et al., 2014; Witol and Webbe, 2003). It has also been shown that subconcussive hits (defined as head impacts inducing no readily observable symptoms) in contact sports have the ability to cause neurophysiological changes that accumulate from one season to the next (Abbas et al., 2015a, 2015b; Bailes et al., 2013; Breedlove et al., 2014). Whether these changes result in long-term deficits likely depends on a variety of, as yet unknown, factors but it has been established that up to 72% of a typical high school football team exhibits changes that persist well into the off season when examined using functional MRI (Breedlove et al., 2014). In addition, resting state functional MRI imaging has demonstrated significant differences between collision sport athletes at their pre-season evaluation and non contact sport controls (Abbas et al., 2015a, 2015b; Bailes et al., 2013; Johnson et al., 2014; Johnson et al., 2012; McKee et al., 2009; Talavage et al., 2014). Taken together, these data indicate that elucidating which physical insults eventually lead to traumatic brain injury requires a characterization of the overall distribution of head impacts experienced by athletes during competition.

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While reported head accelerations for American football can exceed 250 g and the number of head impacts experienced in a season may range from 200–1900 (Breedlove et al., 2012; Broglio et al., 2009, 2012), little is known about head impacts in soccer, and the number experienced by a player over the course of a season is unclear. Soccer-related head accelerations observed in laboratory or controlled settings, and from modeling, are expected to be in the range of 16–25 g for soccer balls traveling between 9 and 12 m/s (Babbs, 2001; Higgins et al., 2009; Naunheim et al., 2003a). However, while many or most measureable head accelerations result from contact with the ball, other players or the ground, the experience of an acceleration does not require a direct impact to the head (e.g., the whiplash-like motion of the head for a player making body contact), and such events have not historically been examined.

Despite its importance to our understanding of head trauma in female athletes, little is known about the number and magnitude of head impacts experienced by female soccer players. Consequently, the goal of this study was to expand on previous research that examined head impacts in controlled situations (Higgins et al., 2009; Naunheim et al., 2003a, 2003b) by quantifying the number and magnitudes of hits sustained by female soccer players over the course of an entire season at both the high school and collegiate level.

2. Methods

2.1. Subjects

Data were collected from 29 female high school athletes (ages: 14–18; mean: 15.7) and 24 female National Collegiate Athletic Association (NCAA) athletes (ages: 17–22; mean: 18.8) across one competitive season. Two high schools were represented: HS1 ($n=12$), HS2 ($n=17$) and one collegiate team ($n=24$). Only data from those athletes wearing the xPatch affixed behind the right ear were used in this study, reducing our collegiate population to 14 athletes (ages: 17–22; mean: 18.7). All research methods involving human subjects were approved by Purdue's Institutional Review Board prior to the initiation of the study. Participant written informed consent was obtained from those 18 years of age and over and both parental consent and participant assent were obtained from all subjects under the age of 18.

2.2. Collision event monitor validation

In-laboratory validation of the xPatch sensors was performed by placing a set of sensors (right ear patch, left ear patch, and headband) on a Hybrid 3 headform (Fig. 1) and applying impact loads using an instrumented mallet. The translational acceleration was obtained from an accelerometer at the head's center of mass and compared to the translational acceleration obtained by the applied xPatch sensors. Impact loads were applied to five different locations on the Hybrid 3 headform (front, left side, right side, back and top). A total of five sensors were tested, each in all three locations on the head (right ear patch, left ear patch and headband), with 50 impacts for each sensor in each location (Supplementary Fig. S1). The xPatch sensor continually measures the translational acceleration and angular velocity. The angular acceleration is obtained by differentiating the angular velocity data. The X2 Biosystems software then outputs peak translational acceleration (PTA) approximated for the head center of mass using the equations for rigid body motion as well as peak angular acceleration (PAA). The root mean square error (RMSE) was calculated for the population to quantify the total differences (bias error and random error) between the ground truth values from the Hybrid 3 headform and the experimental values that were output by the xPatch sensor.

2.3. Collision event monitoring

Head collision events, including games and practices, were monitored using the xPatch (X2 Biosystems; Seattle, WA) during practices and games throughout the entire season. For the purposes of this study, each practice and game was considered an athletic "session." The sensors were affixed to each player's head with an adhesive patch placed behind the right ear. Head impacts were recorded on the sensor when it measured a PTA greater than 10 g. Following each practice and game, the data were downloaded using the Head Impact Monitoring System software (X2 Biosystems, Seattle, WA).

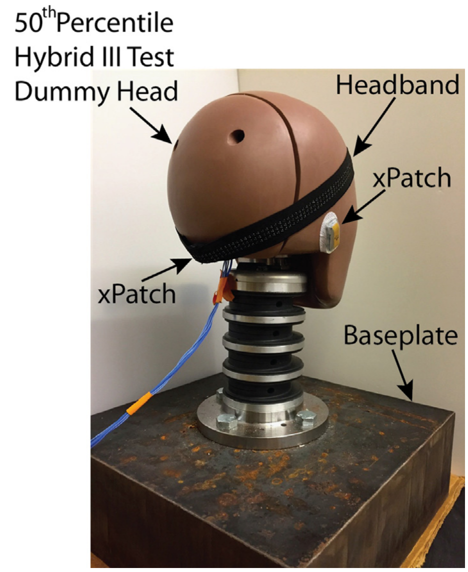

Fig. 1. The testing set up for the Hybrid III test dummy affixed to a 170 lbs baseplate. Three sensors were attached to the head for each round of testing. One was placed behind the right ear, one behind the left (not shown), and one was attached using a thin headband.

2.4. Head collision event data analysis

For the purposes of this study, we did not distinguish between acceleration events caused by direct impacts, whiplash-like motions of the head, falls, or diving to the ground. The sensors were sensitive enough to collect low acceleration events (10–20 g) for hard stops, cuts, and hard kicks. Given that these events are assumed to be unlikely to result in deleterious neurophysiological changes (e.g., there are no reports of sprinters experiencing abnormally high rates of neurological disorders), our analysis on head accelerations was limited to those events surpassing 20 g. It should be noted, however, that any threshold selection will remain somewhat arbitrary until neurophysiological or neurocognitive-based assessments are merged with data sets such as the one described here (Breedlove et al., 2012; Chun et al., 2015; Nauman et al., 2015; Poole et al., 2015; Robinson et al., 2015).

Data from the sensors were processed to remove any impacts recorded prior to placement of the sensor on the athlete or after removal of the sensor. Data was summarized for each player, considering the number of impacts, the average peak translational and angular accelerations and the cumulative peak translational and angular accelerations, cPTA and cPAA, respectively.

3. Results

The xPatch sensor verification demonstrated that the RMSE for sensors worn on the right and left ears were less than 53% for both PTA and PAA (Table 1). Sensors worn as a headband exhibited a 41.7% RMSE for PTA, but 305.4% for PAA. For this reason data from players wearing headbands were not used in the final analysis.

The average PTA sustained by players at the high school level was significantly lower than that of the collegiate players (Table 2) when compared using a two sample t-test ($p \ll 0.05$ for PTA, $p=0.0526$ for PAA). In addition, the collegiate players received more than twice as many impacts per session than high school players. The high school teams took an average of 2.05 hits per session at an average peak linear acceleration of 37.56 g (95% CI [36.94; 38.18]), and an average peak angular acceleration of 7523 rad/s^2 (95% CI [7390; 7656]). In comparison, collegiate players recorded an average of 4.59 hits per session at a significantly higher average peak linear acceleration of 39.31 g (95% CI [38.81; 39.81]), and an average peak angular acceleration of 7713 rad/s^2 (95% CI [7606; 7819]).

Given that the collegiate players took many more impacts throughout the season, their mean cumulative exposure to translational (cPTA) and angular accelerations (cPAA) were significantly higher than those of the high school players ($p \ll 0.05$ for cPTA and