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Mini Review Article

Analyzing Magnitude and Frequency of Video Verified Head Impacts in Relation to Impact Location in Collegiate Soccer Athletes

Sarah Coronel[1*], Debbie A Bradney[2], Sean M Collins[2], Katherine M Breedlove[3,4] and Thomas G Bowman[2]

[1]*Department of Orthopedics, Emory Healthcare, Johns Creek, GA, USA*

[2]*Department of Athletic Training, University of Lynchburg, Lynchburg, VA, USA*

[3]*Center for Clinical Spectroscopy, Brigham and Women's Hospital, Boston, MA, USA*

[4]*Department of Radiology, Harvard Medical School, Boston, MA, USA*

***Corresponding author:** Sarah Coronel, MEd, ATC, Emory Healthcare, 6335 Hospital Parkway, Suite 302 Johns Creek, GA 30097, USA.

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Abstracts

Studying head impact location may provide insight on potential preventative efforts. Our objective was to determine magnitudes and frequencies of head impact locations in soccer athletes. 9 men's (age=18.67±1.00 yr, height=183.57±5.39 cm, mass=80.32±13.50 kg) and 19 women's (age=19.42±1.43 yr, height=166.17±5.24 cm, mass=64.15±7.23 kg) soccer athletes volunteered to participate. Impact location (back, front, side, top) was the independent variable. We compared linear (g) and rotational (deg/s^2) accelerations from xPatch sensors across impact location for video verified head impacts in games and practices using Kruskal-Wallis tests. We calculated incidence rates (IRs) per 1000 athlete-exposures and incidence rate ratios (IRRs) with corresponding 95% confidence intervals (CIs) to determine frequency differences. The effect of location on linear ($\chi 2_3$=34.23, P<.001) and rotational ($\chi 2_3$=47.31, P<.001) acceleration were both significant. Participants were 2.33 times more likely to get hit on the side of the head (IR=113.83, Cl=93.55-134.11) than front of the head (IR=48.92, Cl=35.62-62.21; IRR=2.33, CI=1.68-3.22). Our results suggest a need for coaching emphasis, behavior modifications, and player education to reduce head impacts, especially to the side and front of the head.

Keywords: Head impact biomechanics; X2 Biosystems; xPatch; Futbol

Introduction

Soccer is a physical, contact game that is the most commonly played sport around the world [1]. In soccer, players are not permitted to use their hands unless they are throwing the ball inbounds or are goalkeepers [2]. Instead, players must use their body, head, legs or feet to redirect the soccer ball. Oftentimes players fix their heads in a set position to apply momentum on the ball in a specific direction; a maneuver called heading. According to Gessel et. al., [3] 36.7% of concussions in female soccer players and 40.5% of concussions in males soccer players are caused by collisions while heading the ball. Heading the ball in soccer has been found to alter brain structure and effect short term neurocognitive performance [4]. Recent research has also raised concerns about repeated subconcussive blows, impacts that do not cause a concussion, and the associated possible long term neurological outcomes [5]. Studies have measured the frequency and magnitude, measured by rotational and linear acceleration of head impacts, in an attempt to better understand concussions and subconcussive impacts [1,5-9]. Through quantifying frequency and magnitude of head impacts, potential strategies for minimizing head impacts in sport can be implemented with greater focus.

Mihalik et. al. [10] found that impacts to the top of the head are most common during collegiate football participation while O'Day et. al. [11] found that impacts to the side and front of the helmet occurred most frequently in collegiate lacrosse. Hanlon et. al. [12] found that head impacts occurred most often in the front, followed by the top of the head, then the side, then back in girls youth soccer. The locations with the highest magnitude of impact should be an area of concern because greater accelerations may result in neuropsychological changes or concussion [11]. Therefore, our purpose was to explore the relationship between magnitude and frequency of head impact locations in collegiate soccer athletes. Our hope was findings from further exploring impact biomechanics can be used to increase education, awareness, and prevention of head injuries [1,5-7]. We hypothesized that impacts to the front of the head would be most common due to purposeful heading that occurs during soccer participation.

Materials and Methods

Participants

We recruited men's and women's soccer athletes to participate in this study. Nine male (age=18.67±1 years old, height=184.57±5.39 cm, mass=80.32±13.50 kg) and 19 female (age=19.42±1.43 years old, height=166.17±5.24 cm, mass=64.15±7.23 kg) varsity soccer athletes volunteered. Inclusion criteria included Division III athletes on varsity soccer teams. Exclusion criteria included athletes under the age of 18 and athletes unable to participate due to injury. Throughout the season, there were 57 games and 36 practices total (28 practices and 16 games over 10 weeks for men and 29 practices and 16 games over 11 weeks for women). There were 672 practice athlete-exposures (229 for men and 443 for women) and 391 game athlete-exposures (130 for men and 261 for women).

Instrumentation

We used X2 Biosystem's (Seattle, WA) xPatch sensors to collect data for this study. The xPatch sensor was secured using an adhesive patch from X2 Biosystems and Cavilion (3M, St. Paul, MN) barrier film to help reduce the risk of skin irritation. The xPatch has been used as a tool in other studies because of its ability to measure linear acceleration, rotational acceleration, and frequency of single impacts.[8,13-15] Although the xPatch has also been found to perform better than other measurement devices when predicting the location of impact,[15] it has been shown to overestimate impact magnitude [13]. The xPatch measured the magnitude, frequency, and location (front, back, side, top) of head impacts as described previously [11]. We set the threshold to 10 g; any impact under 10 g was not recorded because typically, activities of daily living occur under 10 g [16]. Practices and games were recorded for verification with a VIXIA HFR600 video camera (Canon, Melville, New York). When transferring the data from the camera, we used a TouchSmart tm 2 laptop (HP, Palo Alto, California).

Procedures

The Institutional Review Board (IRB) granted approval to conduct the study before potential participants were contacted. We informed all members of the men's and women's soccer teams of the study and asked them to participate. Those members who agreed to participate signed a consent agreement form and provided demographic information. We assigned each participant an xPatch sensor which we secured over each participant's right mastoid process using an adhesive patch for all games and practices. A checklist was used to confirm proper application of the xPatch of each participant and to record athlete-exposures daily. At the end of practices and games, participants removed their xPatch sensors and returned them to a research team member. Once collected, we cleaned the sensors with alcohol wipes, uploaded head impact data using the X2 Impact Monitoring System software, and returned them to charge on the docking station.

After we video recorded practices and games with a date and time stamp, we downloaded and saved the videos. The videos of practices and games were used to verify head impacts that could clearly be seen on film [17]. If a head impact could not be verified on the video, it was not included in the final data analysis.

Statistical analysis

After we collected data and verified it using event film, we entered it into the Statistical Package for Social Sciences (SPSS, version 23; IBM Inc, Armonk, NY). The data set was determined to violate normality assumptions and therefore we used Kruskal-Wallis tests to determine magnitude differences based on impact location and Mann-Whitney U tests for post-hoc analyses. The P value was set at 0.05 a priori. We calculated incidence rates (IRs) per 1000 athlete-exposures and incidence rate ratios (IRRs) with corresponding 95% confidence intervals (CIs) to determine frequency differences[18] using Microsoft Excel (Excel 2013, Microsoft, Inc., Redmond, WA).

Results

Descriptive statistics of sustained head impacts across impact location can be seen in Table 1. The effect of impact location on linear (χ23=36.03, P<.001) and rotational (χ23=51.21, P<.001) acceleration were both significant. Follow-up post hoc Mann-Whitney U test results can be found in Table 2. Side impact linear accelerations were significantly lower than front, top, or back (P<.05). Rotational accelerations were higher for front impacts compared to side, top, or back (P<.05) and back impacts were higher than side impacts (P<.001). No other pairwise comparisons were significant when analyzing linear and rotational accelerations (P>.05). We verified 301 head impacts during 1063 total athlete-exposures (IR=283.16, CI95=251.17-315.15). Most impacts occurred to the side of the head (n=154; IR=144.87, CI95=121.99-167.75) followed by back (n=75; IR=70.56, CI95=54.59-86.52), front (n=60; IR, CI95=42.16-70.73) and top (n=12; IR=11.29, CI95=4.90-17.68) (Table 1 & 2).

Table 1: Descriptive statistics of sustained head impacts across impact location.

			95% Confidence Interval					
	Location	**Mean**	**Lower**	**Upper**	**Median**	**Std Dev**	**Minimum**	**Maximum**
Peak Linear Acceleration	Back	25.25	21.54	28.96	19.52	16.12	10.15	76.34
	Front	28.38	24.23	32.53	24.43	16.07	10.33	73.21
	Side	17.69	16.11	19.27	13.71	9.93	10.04	67.12
	Top	24.18	16.76	31.59	20.63	11.67	10.17	51.58
Peak Rotational Acceleration	Back	301014.58	245896.77	356132.39	216610.00	239560.26	1318.63	940172.00
	Front	374929.00	315653.02	434204.97	310822.50	229460.67	79609.40	927732.00
	Side	178518.88	153673.03	203364.73	118236.00	156069.26	1489.45	1130000.00
	Top	189748.23	122257.54	257238.92	195041.00	106222.71	1485.67	369358.00

Table 2: Pairwise comparisons of impact magnitudes across impact location.

		Front	**Side**	**Back**	**Top**
PLA	Front		Z=-5.34, P<.001	Z=-1.52, P=.13	Z=-.65, P=.52
	Side	Z=-5.34, P<.001		Z=-3.83, P<.001	Z=-2.46, P=.01
	Back	Z=-1.52, P=.13	Z=-3.83, P<.001		Z=-.38, P=.71
	Top	Z=-.65, P=.52	Z=-2.46, P=.01	Z=-.38, P=.71	
PRA	Front		Z=-6.76, P<.001	Z=-2.28, P=.02	Z=-2.71, P<.01
	Side	Z=-6.76, P<.001		Z=-4.22, P<.001	Z=-1.16, P=.25
	Back	Z=-2.28, P=.02	Z=-4.22, P<.001		Z=-1.07, P=.28
	Top	Z=-2.71, P<.01	Z=-1.16, P=.25	Z=-1.07, P=.28	

Discussion and Implications

We found that impacts to the side of the head were most common compared to other locations but had the lowest magnitudes. We believe these findings are important as we suspect experiencing many high magnitude impacts would be more detrimental to long term athlete health. However, it remains unknown exactly how low magnitude repetitive impacts alter brain function. In soccer, repetitive heading has been linked to microstructural damage and impaired neurocognitive performance without respect to head impact magnitude [19]. Concentration, attention, and other cognitive abilities have also been predicted by career heading frequency [5]. However, cognition [20,21], and balance [21] have been found to be unaffected by heading soccer balls and cognition has been shown to be unchanged over the course of a collegiate soccer playing career [22]. Therefore, it remains unknown how repetitive low magnitude head impacts may alter both short-term and long-term brain function.

In our study, it was found that soccer players will experience head impacts 2 times out of every 7 game or practice athlete-exposures, or 0.28 head impacts per session. According to McCuen et al, [23] collegiate female soccer players experienced an average of 4.6 impacts per session and high school female soccer players experienced 2 impacts per session. Similarly, Reynolds et. al. [24] found head impact rates much higher than ours; 6-8 impacts per practice and 10-40 impacts per game. Lynall et. al. [25] also found a higher rate at about 7 impacts per 90 minutes of game time. We suspect our use of video confirmation makes our rates much more conservative as the xPatch has been found to overestimate head impacts [17]. Press et. al. [26] also used video confirmation and found a rate that was more comparable, yet still higher, to ours at 1.86 per athlete-exposure.

Frontal head impacts resulted in the highest head accelerations in the current study. Therefore, we believe participants chose to head the ball with the front of their head during events when the ball was moving at high speeds. Caccese et al. [27] found that head accelerations were highest off of goal kicks and punts. Although we did not code the mechanism of impact for this particular study, we believe the findings of Caccese et al. contextualize our findings. It is reasonable to expect heading goal kicks and punts would occur at the front of the head as athletes likely have more time to adjust to the ball in the air.

In 2003, Pellman et. al. [9] conducted research on mild traumatic brain injuries in professional football players finding that most concussions occurred from impacts to the side or front of the helmet. Football players who sustained concussions had a higher likelihood of receiving impacts to the side and top of the head rather than the front on day of concussion [28]. Similarly, impacts to the side of scholastic boy's lacrosse players were most likely to induce concussion [29]. Biomechanical analysis of concussions in women's soccer and lacrosse also found mechanisms of impact to the front or side of the head [30]. Taken together, these previous findings of impacts to the front and side of the head are concerning

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when considering injury prevention. Soccer players sustained head impacts to the front and side most commonly. Perhaps a concussive mechanism is most likely an impact to one of these two areas because the likelihood of impact in these locations is more common. Regardless, we believe these results provide evidence for measures focusing on reducing head impacts to the front and side of the head in collegiate soccer.

We were surprised to find that the majority of the head impacts we verified were to the side of the head. We expected to find an overwhelming majority to be to the front of the head as is common during soccer heading in our experience. Perhaps athletes redirect the ball with the side of their head in various directions more often than using the front of their head to redirect the ball forward. Another possibility is that athletes experience head impacts to the side of their heads more often when fighting for position during 50/50 tackles and headers when contact is made to the side of the head with other heads, elbows, and arms. We base our proposed explanations on the fact that soccer players receive impacts to the head most commonly from ball to head mechanisms and head to body mechanisms [31,32].

Several studies have examined the relationship between neck muscle strength and head impact. Broglio et al. [31] suggested that muscles in the neck should be strengthened and need to be contracted at the moment of impact to help significantly decrease the effective magnitude of the impact. Soccer athletes often brace themselves for impact and engage their neck stabilizers when preparing to contact the ball. Gutierrez et al. [4] investigated the relationship between neck strength and head acceleration/impact in female high school soccer athletes. They found that increased neck strength is related to a decrease in magnitude of impacts during heading. There were no obvious directional relationships, but their findings indicated that overall isotonic neck strengthening was beneficial in decreasing all magnitudes and directions of headers. Dezman et al. [32] also found that symmetrical strength in neck flexors and extensors is correlated to reduced head acceleration during low-intensity heading. Perhaps neck strengthening may be a valuable strategy to decrease the magnitude of head impacts to soccer athletes.

It is suspected that the parameters that determine if and when a concussion occurs are highly individualized [33]. But generally, it has been found that as the frequency of head impacts increases, cognitive function decreases, highlighting that repetitive subconcussive head impacts can affect neurocognitive function similarly to single-impact concussions [5]. It is important that soccer athletes are aware of the potential consequences of head impacts. In addition, coaches and parents may encourage players to implement strengthening of the neck stabilizers to possibly reduce the magnitude of impacts when heading the ball and use judgement when deciding to participate in a tackle or head the ball based off of the situation and their own readiness during that situation. Based on our findings, perhaps frontal plane strengthening should focus on endurance as many smaller magnitude impacts occur frequently to the side of the head while sagittal plane strengthening should focus on attenuating larger magnitude impacts to the front and back of the head.

Limitations & Future Directions

It has been found that the xPatch tends to overpredict the magnitude of impacts and has a 50% error rate for measurement as a result [8], which may have affected our results. In an effort to reduce false positives [17], we filmed each game and practice with a date and time stamp and used the film to verify impacts detected by the xPatches. Although we used a standard coding structure, interpretations of head impacts may have been different amongst research team members. It is important to note that our study included a small number of participants from NCAA Division 3 men's and women's soccer teams. We caution against extrapolating our results to other populations, including youth, scholastic (high school), other collegiate (i.e., D1, D2), and professional soccer. It would be beneficial to conduct larger studies with more participants to increase the total number of athlete-exposures in order to narrow Cls and more accurately solidify the findings and improve generalizability.

Future research should be conducted to continue exploring the effects of skull anatomy on head injuries. Perhaps the frontal bone offers more protection from concussions than the temporal and parietal bones because of its thickness [34,35]. This information could be used to instruct soccer athletes how to position their bodies differently when going up for headers so that they use the front of their head rather than the sides when making contact with the ball if it is confirmed that contact with the frontal bone is safer. In addition, it may provide extra evidence for encouraging soccer athletes to protect the sides of their head from contact with other players when challenging for possession.

Conclusions

Collegiate soccer players sustain many low magnitude impacts to the side of the head. Front impacts recorded significantly higher linear and rotational accelerations, but occurred less frequently. Our results suggest prevention efforts, including neck strengthening, behavior modifications, and education in an effort to reduce head impacts, should be focused on the side and front of the head as impacts to these locations are either frequent or higher in magnitude. Additional studies should be performed to determine the ability of focused interventions to limit head impacts in specific locations.

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Conflict of Interest

Conflict of interest.

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