Magnitude and frequency of head impact among university American football players

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Abstract The purpose of this study was to analyze head impact kinematics at different locations of Japanese university American football players using a 6DOF (degrees of freedom) device. The subjects of this study were 43 players who belonged to T University in the Kanto Collegiate American Football Association second division. We used a Vector Mouthguard (i1 Biometrics Inc.) equipped with a 6DOF to measure the head LA (linear acceleration), AA (angular acceleration) and AV (angular velocity), as well as the number of head impacts during collisions, and evaluated 4 impact locations (front, side, back, and top) in detail. The total number of head impacts was 2,070 during games and 10,007 during practice sessions for a total of 7 games and 41 practices during fall regular seasons over a 2-year period. The most common head impact location was the front (43.5%), followed by the side (41.9%), top (10.9%), and back (3.7%). When classifying the total number of head impacts at these locations according to player position, skill players showed the highest proportion of side impacts ($p < 0.05$), whereas linemen showed the highest proportion of frontal impacts ($p < 0.05$) compared to the other locations. These results support previous studies conducted for university American football players in the United States. That is, the frequency and location of head impacts is greatly influenced by player position. Regarding the magnitude of head impact locations, the LA and AA values for back of the head impacts were the highest both at games and practice sessions. In addition, the AA value for impacts to the top of the head was much higher than the AA value for impacts to the front and side ($p < 0.05$). Also, there were significant positive correlations between peak LA and peak AA at all head impact locations for games and practice sessions based on player position ($p < 0.05$). Skill players showed significant positive correlations between peak AA and peak AV at all head impact locations in games ($p < 0.05$). In comparison, linemen showed significant positive correlations between peak AA and peak AV for frontal and side impacts for games and frontal, side, and top of head impacts in practice sessions ($p < 0.05$). As a result, it was clear that Japanese university American football players could not stabilize the head during collisions. In conclusion, it was found that the frequency of head impact locations in Japanese university American football players was the same as that in the USA. In head impact kinematics during collisions, Japanese university American football players showed different characteristics from their American counterparts. In the future, we should take into account neck muscular strength and motion analysis to better understand the influence of head impacts on Japanese university American football players.

Keywords : American football, 6DOF device, head impact kinematics, impact location, impact frequency, concussion

Introduction

In the past decade, concussion has attracted great interest not only in the United States, but also in Japan¹⁻⁴. According to a report⁴ on trauma research covering a period of more than 20 years, concussion was the third most common type of trauma (8.9%) during official games in

fall seasons of the KCFA (Kanto Collegiate American Football Association) league. Also, from a 10-year injury survey of American football players in universities³, we reported that the concussion rates during games and practice sessions in fall seasons using athlete-exposures (AEs) were 11.1% (3.9/1000 AEs) and 8.4% (0.6/1000 AEs), respectively. These values were higher than those of 5.5% (0.21/1000 AEs) and 6.8% (2.34/1000 AEs) for university students in the US². Athlete-exposures (AEs) are defined

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as the exposure of an athlete to the possibility of injury by participation in games or practices, regardless of the time spent performing the activity.

In the 2000s, many US researchers collected real-time head acceleration data, including linear acceleration (LA) and angular acceleration (AA), during head collisions of American football players using acceleration sensors⁵⁻²². In 2009, a 6-axis sensor (6DOF) equipped with 3-axis acceleration sensors and 3-axis gyro sensors was developed, and the detailed analysis of AA and angular velocity (AV) acting on heads reported since then^{7-9,21,22}. From these results, regarding head impact kinematics at different locations on the head, the following has been clarified in the US. Frontal impacts are the most common location^{5-7,15,16,19,23-25}. The LA value for impacts to top of head is significantly larger than for other locations. On the other hand, the AA value for top of head impacts is significantly smaller than for other locations^{6,13,16,19}. In addition, the location and frequency of head impacts are greatly influenced by player position^{5-7,9,20,23}. For example, offensive linemen have many frontal head collisions and running backs have the highest head LA and AA values^{6,13,19}. For the first time in Japan, head impact kinematics - the number of head impacts and the average peak LA during collisions - of a Japanese university American football player using a 6DOF device was reported by us²². The number of collisions during practice in Japan was significantly higher than that in the USA. Particularly, linemen undergo more head collisions than those of skill players. In addition, the values of average peak LA and AA during games are significantly higher than those during practices. However, head impact kinematics at different locations of the head has not been clarified. It is possible to further understand the characteristics of concussion in American football having different roles, depending on player position, by analyzing head impact kinematics at different head locations. Such data would be valuable in designing preventive measures for concussion. Therefore, it is important to investigate in greater detail different locations of the head where collision occurs and the extent of head impact during collisions⁵. The purpose of this study was to analyze head impact kinematics at different locations of the heads of Japanese university American football players using a 6DOF device.

Method

Subjects. The subjects of this study were 43 players, who belonged to T University in the KCFA second division (27 skill players who handle the ball, such as quarterbacks, running backs, wide receivers, defensive backs, and linebackers, and 16 linemen who face off on the line of scrimmage and make tackles or blocks opponents, such as offensive and defensive linemen, and tight ends, as listed in Table 1). The existing diagnosis of concussions was not considered in the selection of subjects. The purpose

of this study was thoroughly explained to the subjects and consent obtained. Furthermore, this study was performed with the approval of the Tsukuba University Sport Theory Committee (approval number: 28-55).

Measurement method. A Vector Mouthguard (i1 Biometrics Inc.; Fig. 1) equipped with a 6DOF device (a three-axis acceleration sensor and a three-axis gyro sensor) was used to measure head LA and AA during collisions as well as to record head impact locations, and number of head impacts. The sampling frequency of the three-axis acceleration sensor (ADXL377, Analog Devices) was 1024 Hz, which can measure LA of up to 200 G. The sampling rate of the three-axis gyro sensor (L3GD20H, ST Microelectronics) was 760 Hz, which enabled the measurement of AA of up to 2000 deg/s² (34.9 rad/s²). The measurements were conducted during seven games and 41 practice sessions of fall regular seasons over a 2-year period.

Subjects who wore Vector Mouthguards participated for games and practice sessions as usual. When a Vector Mouthguard detected impacts such as tackles, it sent a real-time record of various measured values during collisions to an application on a computer via a receiver (antenna; Fig. 2). The recorded data were computationally up-sampled to 5000 Hz, and the calculations were automatically performed for LA, AA, and head impact locations. In calculations, a low-pass channel frequency class (CFC) 180 filter was used as the acceleration sensor, and CFC 65 was used as the gyro sensor. The measured values recorded in the computer were collected successfully.

Definition of head impact locations. The definition of head impact locations was made according to azimuth and elevation angles in an anatomic coordination system^{7,15,20}. All axes were centered on the center of gravity of the head. Positive x, y, and z axes were oriented toward a) the face on the midsagittal plane, b) the right ear perpendicular to the midsagittal plane, and c) the trunk on the frontal plane, respectively (all axes; Fig. 3). Four locations on the head were classified. The top of the head (top) was defined as an area having an elevation (α) of over 65°, where 0° was considered to be on the horizontal plane passing through the center of gravity of the head. Other head impact locations were defined by azimuth (θ),

Table 1. The physical characteristics of subjects

	Age (year)	Height (cm)	Weight (kg)
ALL (n=43)	20.1 ± 1.2	173.7 ± 5.6	82.4 ± 12.4
Linemen (n=14)	20.1 ± 1.4	176.9 ± 5.9	97.3 ± 7.4
Skill players (n=29)	20.0 ± 1.1	172.2 ± 4.8	75.2 ± 6.4

Fig. 1 Vector Mouthguard (i1 Biometrics Inc.) equipped with 6DOF to measure the head LA and head RA during collisions as well as for recording the HIC values, collision location, and number of collisions.

3DOF Gyro sensors

Sampling 760Hz

Detect up to 2000 deg/S²

(34.9rad/S²) angular acceleration

3-DOF Accelerometers

Sampling 1024Hz

Detect up to 200G linear acceleration

Fig. 2 Remote System for the Vector Mouthguard

When the Vector Mouthguard detected head impacts, it sent a real-time record of various measured values during the collision to the application on the PC through a receiver (antenna).

Fig. 3 Definition of head impact locations

*CG: center of gravity

The definition of head impact locations was made according to azimuth and elevation angles in an anatomic coordination system.

i.e., back (-45° to 45°), front (-135° to 135°), and side [a combination of left and right ($\pm 45^{\circ}$ to $\pm 135^{\circ}$)] (elevation and azimuth; Fig. 3). We excluded the data that could not be classified into these areas from the analysis.

Evaluation items. The impact data of this study was defined as more than 10 G of peak LA. The average values for the number of impacts, peak LA, peak AA, and 95% confidence intervals at head impact locations for each player position (skill players and linemen) were calculated. In addition, the relationship between peak LA and peak AA, as well as between peak AA and peak AV, at different head impact locations was investigated, and the correlation coefficient of each relationship was calculated.

Statistics. IBM SPSS Statistics Ver. 24 (IBM Japan, Tokyo, Japan) was used to perform the statistical analysis and the significance level was set to 5%. We used the Kolmogorov–Smirnov test for assessing normality. The Chi-square test was used to assess whether there was a statistically significant difference between the frequencies of head impacts at different head impact locations according to player position. Residual analysis was performed when a significant difference was observed. The average peak LA and peak AA were compared among the head impact locations using a Kruskal–Wallis test, and when a significant difference was observed, a multiple comparison test was performed using the Mann–Whitney U test for head impact locations. The significance level was adjusted using the Bonferroni method. The Spearman's rank correlation coefficient was used to investigate the relationship between peak LA and peak AA, as well as between peak AA and peak AV.

Results

Number of impacts at different head impact locations.

As listed in Table 2, the total number of head impacts varied among the different head locations, i.e., 1319 times at top of the head (10.9%), 446 times (3.7%) at the back of the head, 5250 times (43.5%) at the front, and 5062 times (41.9%) at the side. In addition, when classifying the total number of head impacts at different locations of the head according to player position, skill players showed 650 times (11.7%) at the top of the head, 380 times (6.8%) at the back, 2054 times (36.9%) at the front, and 2480 times (44.6%) at the side. In comparison, linemen showed 669 times (10.3%) at the top of the head, 66 times (1.0%) at the back, 3196 times (49.1%) at the front, and 2582 times (39.6%) at the side. Although skill players showed the highest proportion of impacts at the side ($p < 0.05$), linemen showed the highest number at the front ($p < 0.05$).

Peak LA and peak AA at different head impact locations.

Table 3 shows the peak LA and peak AA of each impact

location for games and practice sessions. The LA value for the back of the head was the highest both at games and practice sessions, and the back showed a significantly higher LA value compared to other locations ($p < 0.05$). In addition, the top of the head showed a significantly lower LA value at games and practice sessions than that of other locations ($p < 0.05$). As far as AA was concerned, its value for the back of the head was also the highest in the case of both games and practices. A significantly higher AA value for the back of the head was observed in comparison to the front and side, which was not much different than that of the top. In addition, the AA value for the top of the head was much higher than that at the front and side as well ($p < 0.05$). At practice sessions, the back of the head presented a significantly higher AA value than the other three locations ($p < 0.05$), which followed the order of top > side > front.

The relationships between peak LA and peak AA and between peak AA and peak AV for various head impacts for games and practice sessions. head impact Fig. 4 to 7 show the relationship between peak LA and peak AA as well as between peak AA and peak AV, respectively, at different head impact locations for games and practice sessions. There were significant positive correlations between peak LA and peak AA ($p < 0.05$) as well as between peak AA and peak AV ($p < 0.05$) at all head impact locations for games and practice sessions. In addition, when classifying the relationship between peak LA and peak AA as well as between peak AA and peak AV, respectively, at head impact locations for games and practice sessions by player position, skill players showed significant positive correlations between peak LA and peak AA as well as between peak AA and peak AV, respectively, at all head impact locations for games and practice sessions ($p < 0.05$). In comparison, linemen showed significant positive correlations between peak LA and peak AA at the front and side locations for games and at the front, side, and top of head for practice sessions ($p < 0.05$).

Discussion

With the use of a 6DOF as the head impact measurement device, it became possible to further investigate the AA and AV more accurately during a collision⁷⁾. There are some problems associated with the use of a mouthguard equipped with a 6DOF, such as frictional wear between teeth, device defects, and error rates^{26–28)}. However, the error rates are considered to be within an acceptable range because the large amount of data collected by a 6DOF device was taken into account⁷⁾. This ensures the validity and reliability of the results obtained via the Vector Mouthguard used in this study.

We reported the number of head impacts and the average peak LA during collisions; however, the purpose of this study was to analyze head impact kinematics at dif-

Table 2. Distribution of head impact locations for games and practices according to player position

Location \ Category	ALL (n=43)		Skill players (n=27)		Linemen (n=16)	
	ALL	Game	Practice	ALL	Game	Practice
Top	1319 [†] (10.9 %)	143 (6.9 %)	1176 (11.8 %)	650 [†] (11.7 %)	84 (8.8 %)	566 (12.3 %)
						669 [†] (10.3 %)
						59 (5.3 %)
						610 (11.3 %)
Back	446 (3.7 %)	84 (4.1 %)	362 (3.6 %)	380 (6.8 %)	63 (6.6 %)	317 (6.9 %)
						66 (1.0 %)
						21 (1.9 %)
						45 (0.8 %)
Front	5250 ^{*†} (43.5 %)	902 (43.6 %)	4348 (43.4 %)	2054 ^{*†} (36.9 %)	308 (32.2 %)	1746 (37.9 %)
						3196 ^{*†\$} (49.1 %)
						594 (53.4 %)
						2602 (48.2 %)
Side	5062 ^{*†} (41.9 %)	2795 (23.1 %)	488 (23.6 %)	1427 (25.6 %)	263 (27.5 %)	1164 (25.3 %)
						1368 (21.0 %)
						225 (20.2 %)
						1143 (21.2 %)
						2582 ^{*†} (39.6 %)
						439 (39.4 %)
						2143 (39.7 %)
						1214 (18.6 %)
						214 (19.2 %)
						1000 (18.5 %)
Sum	12077	2070	10007	5564	957	4607
						6513
						1113
						5400

The arrow indicates typical impact location in head impact. The values indicate the number of impacts at each impact location. The percentage was calculated by dividing the number of impacts by the sum number.
 * p<0.05 vs. Top; † p<0.05 vs. Back; # p<0.05 vs. Front; \$ p<0.05 vs. Side.

Table 3. The representative values of peak linear acceleration and peak angular acceleration among head impact locations for games and practice sessions according to player position

Location	Representative value	ALL		Skill players		Linemen	
		Game	Practice	Game	Practice	Game	Practice
Top		Mean±SD	19.3±12.0 G	17.0±11.3 G	19.9±11.9 G	18.5±12.2 G	15.8±10.5 G
	Acceleration	50 th percentile	14.7 G	13.2 G	16.2 G	13.9 G	13.0 G
	Peak Angular Acceleration	Mean±SD	1535.0±1088.7 rad/sec ²	1147.7±1004.2 rad/sec ²	1627.0±990.6 rad/sec ²	1404.0±1211.6 rad/sec ²	988.0±939.6 rad/sec ²
Back		50 th percentile	1329.3 rad/sec ²	754.7 rad/sec ²	1524.0 rad/sec ²	1116.2 rad/sec ²	648.4 rad/sec ²
	Peak Linear Acceleration	Mean±SD	25.5±11.2 G ^{†‡}	26.5±13.9 G ^{†‡}	27.5±10.3 G ^{†‡}	19.3±11.7 G	16.9±10.6 G ^{†‡}
	50 th percentile	23.0 G	23.5 G	26.5 G	26.0 G	16.0 G	13.9 G
Front		Mean±SD	1796.7±1186.6 rad/sec ² [†]	1725.5±1023.4 rad/sec ² ^{†‡}	1914.1±1144.7 rad/sec ² ^{†‡}	1444.5±1267.8 rad/sec ²	1270.9±650.1 rad/sec ² [*]
	Acceleration	50 th percentile	1386.6 rad/sec ²	1441.4 rad/sec ²	1523.3 rad/sec ²	1103.7 rad/sec ²	1216.8 rad/sec ²
	Peak Angular Acceleration	Mean±SD	1246.9±768.8 rad/sec ² [*]	1101.1±674.6 rad/sec ² [*]	1282.1±951.8 rad/sec ² ^{**}	1228.6±654.3 rad/sec ²	1120.4±541.3 rad/sec ² ^{**}
Side		50 th percentile	1050.3 rad/sec ²	960.8 rad/sec ²	1019.9 rad/sec ²	866.5 rad/sec ²	1016.1 rad/sec ²
	Peak Linear Acceleration	Mean±SD	22.5±13.0 G [*]	19.7±9.4 G [*]	24.0±14.9 G [*]	20.8±10.1 G [*]	18.6±8.4 G [*]
	50 th percentile	18.2 G	16.7 G	19.3 G	17.7 G	17.6 G	16.1 G
Side		Mean±SD	1319.7±892.1 rad/sec ²	1145.7±740.3 rad/sec ² [*]	1429.7±1004.3 rad/sec ²	1193.8±724.3 rad/sec ²	1054.5±581.1 rad/sec ² [*]
	Acceleration	50 th percentile	1099.5 rad/sec ²	968.5 rad/sec ²	1184.1 rad/sec ²	1021.0 rad/sec ²	923.4 rad/sec ²
	Peak Angular Acceleration	Mean±SD	1099.5 rad/sec ²	968.5 rad/sec ²	1184.1 rad/sec ²	1021.0 rad/sec ²	923.4 rad/sec ²

The arrow indicates typical impact location in head impact. * p<0.05 vs. Top; † p<0.05 vs. Front; ‡ p<0.05 vs. Side.

Fig. 4 The relation between peak linear acceleration and peak angular acceleration at head impact locations in games

Vertical axis: Angular acceleration (rad/s^2)

Horizontal axis: Linear acceleration (G)

There were significant positive correlations between peak LA and peak AA at all head impact locations in games by positions ($p < 0.05$).

ferent locations of the heads of American football players in Japanese universities. Regarding the proportion of head impacts that occurred at different locations, the front of the head (43.5%) was the most common, closely followed by the side (41.9%), top (10.9%), and back (3.7%). These results are consistent with the results from many studies^{5-7,15,16,19,23-25}. That is, it is thought that the proportion of head impacts relies on football-specific characteristics, which are not related to competition level or race. Since offensive and defensive players face and collide with each other, it is easy to understand why many head impacts occur at the front and side. As far as the back of the head is concerned, it is assumed that it usually collides with the ground when a player falls after a collision. The back of the head also suffers from collisions from blind spots in a crowded area near a ball carrier or quarterback sacks⁵. Therefore, a shock-absorbing function for such areas becomes important due to the many unexpected collisions that could occur. For the proportion of head impact

locations according to player position, skill players experienced the most head impacts on the side during games (52.5%) and practices (42.9%). Offensive skill players seem to perform unique and complicated movements, such as cutting and changing speeds, to avoid being tackled; the defensive players react to these movements. Consequently, head impacts on the side would be more common than frontal impacts. However, university skill players in the US experience the most head impacts at the front⁵. In short, Japanese university skill players may not be adopting proper body positions against opponents during collisions and thus, a biomechanical approach should be considered to collisions. As to linemen, most collisions occur at the front of the head in games (53.4%) and practices (48.2%), which is in agreement with many previous studies^{6,13,19}. Offensive and defensive linemen seem to have many frontal head impacts, since they collide linearly from a short distance faceoff with each other. Therefore, we should consider that the frequency and location

Fig. 5 The relation between peak linear acceleration and peak angular acceleration at head impact locations in practice sessions

Vertical axis: Angular acceleration (rad/s²)

Horizontal axis: Linear acceleration (G)

There were significant positive correlations between peak LA and peak AA at all head impact locations in practice sessions by positions ($p < 0.05$).

of head impacts are greatly influenced by player position^{5,6,13,16,19}. These data can contribute to the improvement of position-specific helmets⁵. Although we have made comparisons with American university players, due to a lack of Japanese biomechanical data on head impacts using a 6DOF device in vivo, the comparison may be unclear due to differences in physique and competition level of Japanese players compared to university players in the US²⁹.

Regarding head impact kinematics at different locations of the head, the values of peak LA and peak AA at the back of the head were significantly greater than at other head impact locations for games and practice sessions. However, this result disagrees with the results of many studies that found values of peak LA for the top of the head^{6,7,9,19} and peak AA for frontal impacts^{9,30} to be largest in the US. As mentioned above, unexpected collisions with the ground or players from a blind spot at the back of the head are cited as factors. As with collisions from

the back, further consideration could be taken based on helmet improvement and rule revision in the future. Next, a collision at the top of the head in American football, called a spearing tackle, is regarded as the most dangerous because the heavy burden of axial loading can cause cervical spine injuries or quadriplegia³¹, despite many studies reporting peak LA to be the largest and peak AA the smallest at the top of the head in the US^{6,7,9,19}. Mihalik et al. reported that impacts of peak LA 80 G or greater to the top of the head could occur at least 6.5 times greater compared to the back⁶. In other words, a spearing tackle, which is prohibited according to the rules, can be considered as a characteristic at the time of a collision with the top of the head in the US. In contrast, the value of peak LA at the top of the head in Japan was significantly smaller than the peak LA values at the front and side, whereas the value of peak AA at the top was higher than the values at the front and side. That is, in Japan, head impact kinematics for the top of the head is weak, and the head

Fig. 6 The relation between peak angular acceleration and peak angular velocity at head impact locations in games

Vertical axis: Angular acceleration (rad/s²)

Horizontal axis: Angular velocity (rad/s)

Skill players showed the significant positive correlations between peak AA and peak AV at all head impact locations in games ($p < 0.05$). In comparison, linemen showed the significant positive correlations between peak AA and peak AV at the front and side in games ($p < 0.05$).

rotates during a collision. Japanese university players may perceive that impact to the top of the head is more dangerous based on these results. In addition, the contact techniques of Japanese university players could be different from those of their American counterparts. Regarding the top of the head, many authors^{6,7)} also confirmed impacts of 10% to 20%, although the regulated area might be large³²⁾. Results show many more impacts at the top of the head, which was far beyond our expectations⁶⁾.

When analyzing head kinematics LA and AA have been considered independently for the mechanism of concussions^{9,33)}. This is because it is generally accepted that LA is mainly related to the focal (specific location) influence on the brain, i.e., the intracranial volume pressure response, and AA is mainly related to the diffuse (wide-spread) influence on the brain, i.e., the strain response of the brain. However, both LA and AA act on the head at the same time in the case of a collision^{9,33)}. And, a 6DOF

device can more accurately measure AV with a gyro sensor⁷⁻⁹⁾. The results of this study, showing a positive correlation between the peaks of AA and AV at all impact locations of the head, support the study by Rowson et al.⁷⁾. In other words, as time passes, the angular velocity of the head gradually increases due to positive values of angular acceleration. This seems to be a characteristic of collisions in American football. Next, a positive correlation between the peaks of AA and AV at different impact locations of the head based on player position was seen at all locations in skill players, but was only seen at the front and side locations in linemen. Although the back of the head did not show a significant difference, there was a weak correlation. As far as both the top and back are concerned, it could be considered a limited sample size. In addition, a positive correlation was observed between peak LA and peak AA at all impact locations of the head, supporting the results of Pellman et al., who analyzed

Fig. 7 The relation between peak angular acceleration and peak angular velocity at head impact locations in practice sessions

Vertical axis: Angular acceleration (rad/s^2)

Horizontal axis: Angular velocity (rad/s)

Skill players showed the significant positive correlations between peak AA and peak AV at all head impact locations in practice sessions ($p < 0.05$). In comparison, linemen showed the significant positive correlations between peak AA and peak AV at the front, side, and top in practice sessions ($p < 0.05$).

the scenes of concussive impacts among NFL players selected by a video, and used the Hybrid III dummy to reproduce the scenes³⁴). That is, the head rotates extensively as a large LA acts on it. There was the same trend when considering the relationship between peak LA and peak AA at head impact locations based on player position. In contrast, Rowson et al., who conducted an *in vivo* study with a 6DOF device during actual games, did not find a correlation between peak LA and peak AA⁹). He also mentioned that the reason for the difference was that the Hybrid III dummy neck was stiff, which was likely to cause a uniform response to the impact⁹). In this study, the reason for the correlation between peak LA and peak AA at different head impact locations is that Japanese university players may not have sufficient neck muscular strength to stabilize the head during collisions. About 20% of the bones and ligaments of the neck and 80% of the muscles are generally responsible for mechanical

stabilization of the cervical spine. Players contract neck muscles to increase the rigidity of the head, neck, and upper back during collisions^{30,35-37}). Actually, Collins et al. stated that neck strength was significantly related to a concussion³⁸). Therefore, it seems that neck muscular strength has a significant influence on the relationship between peak LA and peak AA; however, because these relationships were not examined in this study, it remains uncertain. Future work could involve taking into account neck muscular strength and motion analysis of the neck at the moment of collision.

Many researchers are trying to compute the concussion risk using peak LA, peak AA, collision locations, or these three variables in combination^{8,15,18,25,26,34}). There were many studies that indicated that the value of peak AA for impact to the front of the head was the largest value among impact locations in the US^{9,19,25,30}); however, there was disagreement on whether the most dangerous

impact location leading to a concussion is the top of the head^{6,8,38,39} or the front^{6,30}. For American football players in the US, it was reported that the values of concussive impacts range from 69.7 to 145 G in peak LA and 7688 rad/s² in the 95th percentile AA^{8,24,26,38,40-42}. However, determination of the probability that head impacts of peak LA over 80 G actually caused concussions varied from 0.28% to 0.38%^{6,13,26}. The low specificity of misidentifying a nonconcussive impact as a concussive impact is an ongoing problem^{6,13,26}. In this study, one concussion, that occurred at the side of the head, was confirmed (peak LA 72.5 G and peak AA 4380.9 rad/s²); but large amounts of data are needed to obtain concussion risk values in Japan. And those values may be different according to head impact location. Furthermore, 52% of players who experienced concussions did not report them^{43,44}; this makes it more difficult to estimate the concussion risk values. Moreover, there are some unavoidable limitations regarding the measurement device. First, the acceleration sensor cannot discern whether a player is tackling or whether a player is being tackled. Also, the mouthguard sensor cannot measure brain movement, which can damage brain tissue due to independent movement in the skull, during head impacts⁴⁵. In short, we should take into account neck muscular strength and motion analysis to better understand the influence of head impacts on Japanese university American football players.

In conclusion, we analyzed the head impact kinematics at different locations of the head for Japanese university American football players using a 6DOF device. It was clear that the front of the head was the most common impact location, closely followed by the side, top, and back. In addition, the peaks of AA and AV values show a positive correlation at all impact locations of the head. These findings seem to be American football-specific characteristics. Finally, a 6 DOF device could be a useful tool for research or quantitative assessment in the field if a given player does not experience head and neck trauma once he suffers a head impact that is above a certain level; but we should be careful of assuming a concussion without sufficient diagnosis^{15,17,46}.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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