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Title:

Effect of repeated head impacts on the amount of the cervical vertebral translation among university American football players.

Running title:

Head impacts and cervical changes in college American football

Authors:

Saaya Umeoka[1]*, Satoru Nishida[2], Takashi Fukuda[3]

Affiliations:

1. Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8577, Japan
2. Faculty of Sport and Health Sciences, Ryutsu Keizai University, 120 Hirahata, Ryugasaki, Ibaraki 301-8555, Japan
3. Faculty of Health and Sports Science, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8577, Japan

Correspondence author's e-mail address:

s.y.ume41@gmail.com

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Abstract

American football is associated with a high risk of cervical injuries. In order to prevent these injuries, head acceleration during head impacts is currently being studied, but no studies have examined the effects on the neck. We aimed to examine the effects of head impact kinematics (the number of head impacts, maximum head linear acceleration [LA], and maximum head angular acceleration [AA]) on cervical vertebral translation in collegiate American football players over a one-year period. 22 players (5 linemen and 17 skill players) who belonged to T university in the Kantoh Collegiate American Football Association Division 2. We examined the relationship between the total number of head kinematics over a year period and the amount of the cervical vertebral translation as measured by a mouth guard with a 6-axis accelerometer. The total number of head impacts of the subjects was 12,368. For skill players, the 4th cervical vertebral movement distance was significantly correlated with the maximum AA (r = 0.49, *P* = 0.04) and also with the maximum LA (*r* = 0.48, *P* = 0.05). In Japanese university American football players, it was suggested that the repeated head impacts with large maximum LA and AA generated in the head affected the amount of the 4th cervical vertebral translation. In particular, skill players were affected, so they need to acquire accurate tackle skills even with a tackle with speed. This may result in a decrease in acceleration during head impact, leading to a decrease in the load on the cervical spine.

Key words: American football, collision sports, repeated head impacts, head acceleration, cervical alignment

Title:

大学アメリカンフットボール選手における繰り返しの頭部衝突が頚椎椎体移動に与える影響

Authors:

梅岡沙綾[1]*, 西田智[2], 福田崇[3]

Affiliations:

1. 筑波大学大学院　人間総合研究科スポーツ医学専攻

2. 流通経済大学　スポーツ健康科学部

3. 筑波大学　体育系

Abstract

アメリカンフットボールは，頚椎損傷のリスクが高いと報告されている．これらの傷害を予防するために，近年は頭部衝突時の頭部加速度について研究が行われているが，頚部への影響について検討した研究はない．本研究では，大学アメリカンフットボール選手において，頭部衝突時のキネマティクス（頭部衝突の回数，最大直線加速度［LA］，最大角加速度［AA］）が頚椎椎体移動に及ぼす影響を 1 年間にわたり検討することを目的とした．関東大学アメリカンフットボール連盟 2 部リーグの T 大学に所属する選手 22 名（Linemen: 5 名，Skill players: 17 名）を対象とした．6 軸加速度計付きマウスガードで測定した 1 年間の頭部衝突時のキネマティクスと各頚椎椎体移動量との関係を検討した．対象者の頭部総衝突回数は 12,368 回であった．Skill players では，第 4 頚椎椎体移動量は最大 AA（$r = 0.49, P = 0.04$）と有意な相関があり，最大 LA（$r = 0.48, P = 0.05$）と有意

な相関の傾向があった．日本の大学アメリカンフットボール選手において，頭部に生じる高い最大 LA と AA を伴う頭部衝突の繰り返しが第 4 頚椎椎体移動量に影響を与えることが示唆された．特に，Skill players が影響を受けており，スピードのあるタックルでも正確なタックル技術を習得する必要がある．その結果，頭部衝突時の加速度が減少することで頚椎への負荷が減少することが考えられる．

Introduction

As a collision sport, American football places players at risk for injuries, especially cervical injuries such as cervical spine contusion[1,2]. Studies have reported that X-ray radiography and magnetic resonance imaging (MRI) are useful diagnostic tools that can identify risk of neck injuries in American football athletes, which can guide intervention to prevent serious injuries. The anterior-posterior canal diameter of the cervical spine (Torg-Pavlov's ratio), which is used as an indicator of spinal canal stenosis, can be measured by X-ray and MRI; Torg et al. reported that athletes with a Torg-Pavlov's ratio of ≤ 0.8 are more likely to sustain serious cervical injuries (e.g., transient quadriplegia)[3]. It has been reported that, in addition to Torg-Pavlov's ratio, changes in cervical spine alignment and vertebral body degeneration occur due to longer athletic experience[4,5]. Changes in cervical alignment induce the straightening of the cervical spine, which can lead to fracture or dislocation of the vertebral bodies due to axial pressure from vertical forces of the parietal region. In addition, a previous study reported that degeneration of the vertebral bodies and intervertebral discs of the cervical spine can be a factor in the development of Burner's syndrome[6]. Therefore, it is recommended to assess the athletes' physical characteristics, including cervical X-ray radiography, as part of pre-season medical testing to prevent severe cervical injuries[7,8].

The reason for the change in cervical spine alignment may be due to a change in the balance of muscle strength between cervical extensors and flexors as well as the repetitive force of head impacts. Simultaneous contraction of the cervical flexion and extension muscles is important to stabilize the cervical spine; a previous study reported that a cervical flexion strength and extension strength ratio of 0.8 was required to prevent cervical spine injuries[9]. Moreover, immobilizing the neck during head impact affects cervical alignment, because the forward compression force of the cervical vertebrae occurs due to muscle hypertrophy of the deep cervical muscles and shortening of the deep flexor muscles of the neck[10,11]. Research of head impacts in American football athletes has been conducted mainly in the U.S. and usually uses the accelerometers to quantify the head impact kinematics. In a study from Japan, the total number of head impacts recorded for 3 games and 22 practices was 8,316, and the median total number of head impacts per person was 40.5 during the game and 282 during practice. The average maximum head linear acceleration (LA) per one head impact was reported to be 20.8 ± 12.1 G during the game and 19.0 ± 10.1 G during practice[12]. Interestingly, the number of head impacts per person per practice session in Japan was more than double compared with data from the U.S.; thus, it is thought that frequent head impact causes a higher cumulative load on the neck in Japanese athletes playing American football. However, there is no study that reported the effects of repetitive head impacts on the cervical spine. Therefore, in this study, we aimed to examine the effects of head impact kinematics (the number of head impacts, maximum head LA, and maximum head angular acceleration [AA]) on cervical vertebral movement in collegiate American football players over a one-year period.

Materials and methods

Participants

In this study, we included 22 Japanese university American football players who belonged to T university in the Kantoh Collegiate American Football Association Division II. The exclusion criteria of participants were as follows: 1) the head collision data could not be measured for three months or more; 2) cervical X-rays could not be taken; or 3) the 7th cervical spine image could not be seen on cervical X-ray radiography. Participants were categorized into linemen and skill players according to their position (5 linemen and 17 skill players). We thoroughly explained the purpose of the study to the subjects and obtained their consent. This study was performed with the approval of the Tsukuba University Sport Theory Committee (approval number: 29-86).

Experimental design

The measurement period was from April 22, 2017, to November 25, 2017, for a total of 218 days. Head impact kinematics were observed in 11 games (5 games in the spring season and 6 games in the fall season) and 117 practices. Cervical X-rays were taken twice by the same radiologist in April before the spring season and in November after the autumn season.

Head impact kinematics

We measured the head impact kinematics such as the number of head impacts, maximum head linear acceleration (LA), and maximum head angular acceleration (AA) using Vector Mouthguard (i1 Biometrics Inc, WA; Figure 1), using a modified measurement method of the one used by Fukuda et al. [12]. It equipped with 6DOF(a three-axis acceleration sensor and a three-axis gyro sensor), the sampling frequency of the three-axis acceleration sensor(ADXL377, Analog Devices) was 1024 Hz, and it can measure LA up to 200 G. The sampling rate of the three-axis gyroscope (L3GD20H, SH Microelectronics) was 760 Hz, and it can measure AA up to 2000 deg/s^2 (34.9 rad/s^2). When a player wearing a mouthguard experienced a head impact, data of the head impact was recorded in an application on the personal computer. The maximum LA and maximum AA were calculated automatically, and data recorded on the personal computer was extracted as Excel data and analyzed.

Figure 1 around here

The amount of the cervical vertebral translation

We calculated the amount of the cervical vertebral translation using the cervical spine curve morphology classification method[13,14]. A straight line drawn at the inferior edge of the posterior margin of the 2nd through 7th cervical vertebrae was defined as the baseline, and a vertically line drawn from that baseline to the inferior edge of the posterior margin of each vertebra was defined as the curvature distance (Figure 2). In addition, the amount of movement of the curvature distance of each vertebra from April to November was defined as the amount of the cervical vertebral translation, which was calculated as an absolute value.

Figure 2 around here

Evaluation items

In this study, we set the cutoff value of the maximum LA at 10 G. We calculated the total number of head impacts, total maximum LA, and total maximum AA, then investigated whether each of these values was related to the vertebral movement distance of the cervical spine.

Statistical analyses

We used the Kolmogorov–Smirnov test to assess the normality of the measures. The cumulative total number of head impacts, maximum LA, and maximum AA derived from the linemen and skill players and average curvature distance and the amount of the cervical vertebral translation for each of the cervical vertebrae were compared by an unpaired *t*-test. The Mann–Whitney *U* test was used to compare the ratio of head impacts by maximum LA and maximum AA between the linemen and skill players. We used the Spearman's rank correlation coefficient to examine the relationship between the cumulative amount of each measurement of head impact and the amount of the cervical vertebral translation. An α level of $P < 0.05$ was considered statistically significant and $P < 0.10$ was significant trends. Statistical analyses were performed using IBM SPSS Statistics version 22 (IBM Japan, Tokyo, Japan).

Results

Head impact kinematics

The total number of head impacts was 12,368, of which 2,493 (20.2%) occurred during games and 9,201 (74.4%) occurred during practice sessions. The average total number of head impacts per person was 562.2 ± 397.2. The average total maximum LA per person was 12,478.6 ± 8,290.2 G and the average was 22.7 ± 2.3 G for one head impact. The average total maximum AA per person was 928,525.8 ± 586,953.0 rad/s^2, and the average was 1,732.6 ± 356.4 rad/s^2 for one head impact.

The total number of head impacts among linemen (956.2 ± 461.2) was larger than that of skill players (446.3 ± 301.8) (P = 0.008). The average total maximum LA of linemen (19,741.5 ± 9,137.8 G) was higher than that for skill players (10,342.5 ± 6,928.1 G) (P = 0.022). We calculated the percentage of the total number of head impacts per maximum LA and maximum AA for each group by taking into account differences in body size (Figure 3). As shown in Figure 3, the percentage of total head impacts by maximum LA in skill players at 40 G $< X \leq$ 50 G was significantly higher than in linemen (P = 0.003) and tended to be higher than in linemen at 50 G $< X \leq$ 60 G (P = 0.071).

There was no significant difference in the average total maximum AA between position (linemen: 1,278,423.0 ± 593,424.3 rad/s^2 vs. skill players: 825,614.8 ± 560,914.4 rad/s^2). As shown in Figure 4, the percentage of total head impacts by maximum AA in linemen at 0 rad/s^2 $< X \leq$ 1,000 rad/s^2 was significantly higher than in skill players (P = 0.019). By contrast, the percentage of total head impacts by maximum AA in skill players at 2,000 rad/s^2 $< X \leq$ 3000 rad/s^2 was significantly higher than in linemen (P = 0.05) and tended to be higher than in linemen at 3,000 rad/s^2 $< X \leq$ 4,000 rad/s^2 (P = 0.058).

Figure 3 around here

Figure 4 around here

The amount of the cervical vertebral translation

Table 1 shows the curvature distance and the amount of the cervical vertebral translation. The amount of the cervical vertebral translation for all subjects were 1.9 ±

1.5 mm for the 4th cervical vertebra and 2.0 ± 1.5 mm for the 5th cervical vertebra, which were longer than those for the 3rd and 6th cervical vertebral body.

Table 1 around here

Correlation between the head impact kinematics and the amount of the cervical vertebral translation

Table 2 show the correlation between the kinematic characteristics and movement distance of each cervical vertebra at the time of head impact. As shown in Table 2, there was a significant correlation between the total maximum AA and the amount of the 4th cervical vertebral translation in skill players ($r = 0.49$, $P = 0.04$), but not in linemen ($r = -0.05$, $P = 0.93$). Similarly, the total maximum LA tended to correlate with the amount of the 4th cervical vertebral translation ($r = 0.48$, $P = 0.05$) in skill players. In linemen, significant correlations were found between the total number of head impacts ($r = 0.900$, $P = 0.04$), total maximum AA ($r = 0.900$, $P = 0.04$), and the amount of the cervical vertebral translation.

Table 2 around here

Discussion

The objective of our study was to clarify the effects of head kinematics caused by repeated head impacts on the neck. The most important finding was that the amount of the 4th cervical vertebral translation is affected by repeated head impacts with high head acceleration. These results provide concrete evidence for the abstract hypothesis that athletic experience influences cervical spine movement.

To the best of our knowledge, this was the first study to examine the total number of head impacts that occur in football players over a one-year period in Japan, including during the spring and summer period when there are many practice days. In the present study, the total number of head impacts was 12,368 in 11 games (2,493, 20.2%) and 117 practices (9,201, 74.4%). A previous study reported that 70% of the total number of head impacts occurred during practice in the U.S[15]. The average number of practice days per year is reported to be approximately 190 days in Japan[2] and 90–100 days in the U.S. [1], which is nearly twice as many days in Japan than in the U.S. Therefore, the percentage of total head impacts that occur during practice was thought to be much higher in Japan than in the U.S., although the present results show that it is only slightly higher than in the U.S. The reason that the results differed from the hypotheses may be that the head-up football has started to spread in Japan, which involves basic practices aimed to acquire a tackling posture without increasing the risk of head impact. Future studies should examine head impacts throughout the year, considering the different practice days that occur in each period. Regarding the difference in position, the number of head impacts in skill players was significantly lower than in linemen. In recent study, it was showed that in positional comparisons of total head collisions, Defensive linemen, one of the linemen positions, have the most collisions and Wide receivers, one of the skill players positions, have the least[16]. This was because skill players spend much of their time practicing techniques with the ball, such as agility and reaction, so the number of impacts to the head during practice is relatively low. The results of the present study agree with findings of earlier studies.

When the total number of head impacts was classified according to LA and AA, skill players had a significantly higher percentage than linemen for 40 G < X ≤ 50 G. In Japan, the median of the maximum LA for a single head impact was reported to be 15.87 G in practice and 16.77 G in games, and the range of difference by position was high LA[13]. The Defensive backs and Wide receiver performed by the skill players are concentrating on catching the ball or running; therefore, they are often tackled at unexpected times or in a posture with insufficient reserve motion and are thus more susceptible to higher maximal LA and AA.

The relationship between the amount of the cervical vertebral translation and head impact kinematics was not correlated with the total number of head impacts in all subjects. By position, skill players showed a significant correlation between 4th cervical vertebral translation and AA, while LA trends in significant correlations. As discussed earlier, the head impact of skill players is characterized by a high percentage of total head impacts by maximum LA and maximum AA, which indicates that repeated high head acceleration, even a small number of times, may have an effect on the amount of the 4th cervical vertebral translation. On the other hand, linemen showed a negative correlation between the amount of the 3rd cervical vertebral translation and total number of head impacts and total maximum LA, although this was difficult to examine due to the small number of subjects. Since the number of linemen per team in Japan is limited, collecting data from multiple teams is necessary for future studies to confirm the findings of the current study.

The cervical vertebrae are classified as upper cervical vertebrae (1st and 2nd cervical vertebrae), middle cervical vertebrae (3rd to 5th cervical vertebrae), and lower cervical vertebrae (6th and 7th cervical vertebrae). The mobility of flexion and extension between the 4th and 6th cervical vertebrae is particularly wider than other cervical vertebrae[17]. Many neck injuries in American football occur in the 3rd to 6th cervical vertebrae; in particular, Burner’s syndrome is a common injury in the middle and lower cervical vertebrae[10,11]. Therefore, it was suggested that the total maximum LA and total maximum AA were affected the 4th cervical vertebra, which has a wide range of motion in this study.

Limitations in this study should be addressed. In a previous study, it was reported that cervical spine alignment changes often occurred after 3 to 6 years of competition experience[13]. Therefore, longer study time is needed to investigate long-term effects. In addition, we did not analyze the position of head impact in this study. The cervical spine undergoes flexion, extension, lateral flexion, and rotation, and the movement of the cervical spine changes in a complex manner depending on the position of the head impact. Therefore, a future study should aim to study the effect of the head impact position on the neck.

The present study revealed that repeated head impacts with a large maximum LA and AA to the head affect the movement of the cervical spine in Japanese collegiate American football players. To reduce adverse effects on the neck, it is important to ensure that players perform head-up tackling and develop a safe tackling posture such as shoulder tackling, in which the tackle comes from the shoulders rather than from the head. In addition to reducing the number of head impacts, it is also important to ensure that skill players tackle accurately, even when accelerating.

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Conflict of interest

The authors have declared that no competing interests exist.

Author Contributions

SU (Saaya Umeoka): study design, participants recruitment, data collection, data analysis, manuscript preparation. SN: study design, data analysis, manuscript revision. TF: study design, data collection, data analysis, manuscript revision. All authors have read and approved the manuscript.

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Figure legends

Figure 1. Vector Mouthguard (i1 Biometrics Inc.)

Figure 2. The cervical spine curve morphology classification method

The baseline was defined as 1) a straight line at the lower edge of the posterior margin of the 2nd through 7th cervical vertebrae, and 2) the curvature distance was measured from the baseline to the lower edge of the posterior margin of each vertebra.

Figure 3. Position-related difference in the percentage of total head impacts by maximum LA.

[a] Significant difference between linemen and skill players ($P < .05$). [b] Trends in significant differences between linemen and skill players ($P < .10$).

Figure 4. Position-related difference in the percentage of total head impacts by maximum AA.

[a] Significant difference between linemen and skill players ($P < .05$). [b] Trends in significant differences between linemen and skill players ($P < .10$).

Figure 1. Vector Mouthguard (i1 Biometrics Inc.)

Saaya Umeoka, Figure 1.

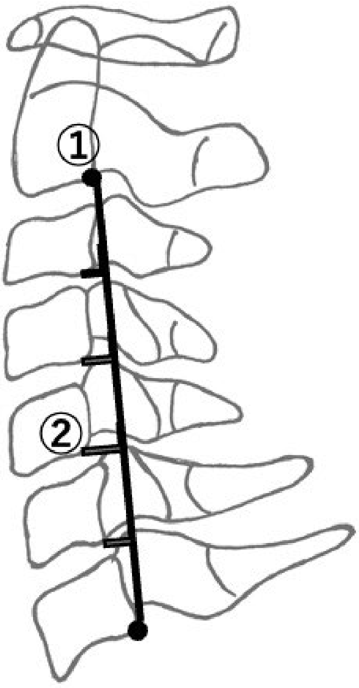

Figure 2. The cervical spine curve morphology classification method

Saaya Umeoka, Figure 2.

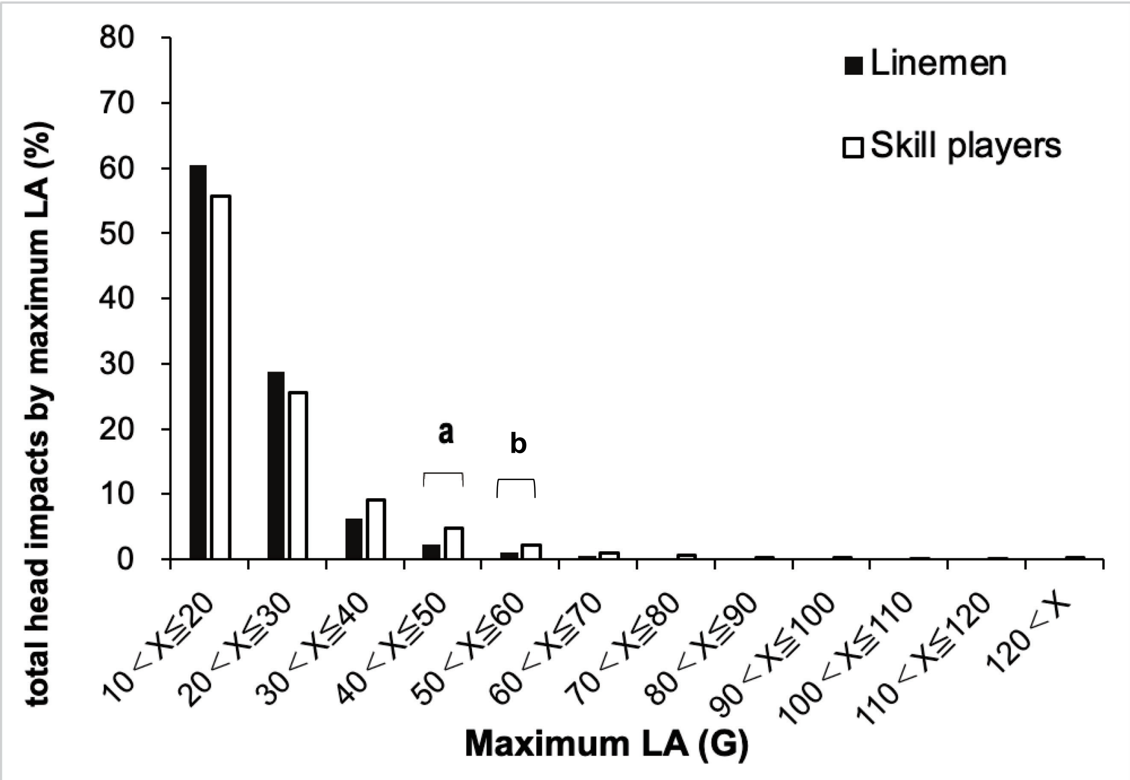

Figure 3. Position-related difference in the percentage of total head impacts by maximum LA.

Saaya Umeoka, Figure 3.

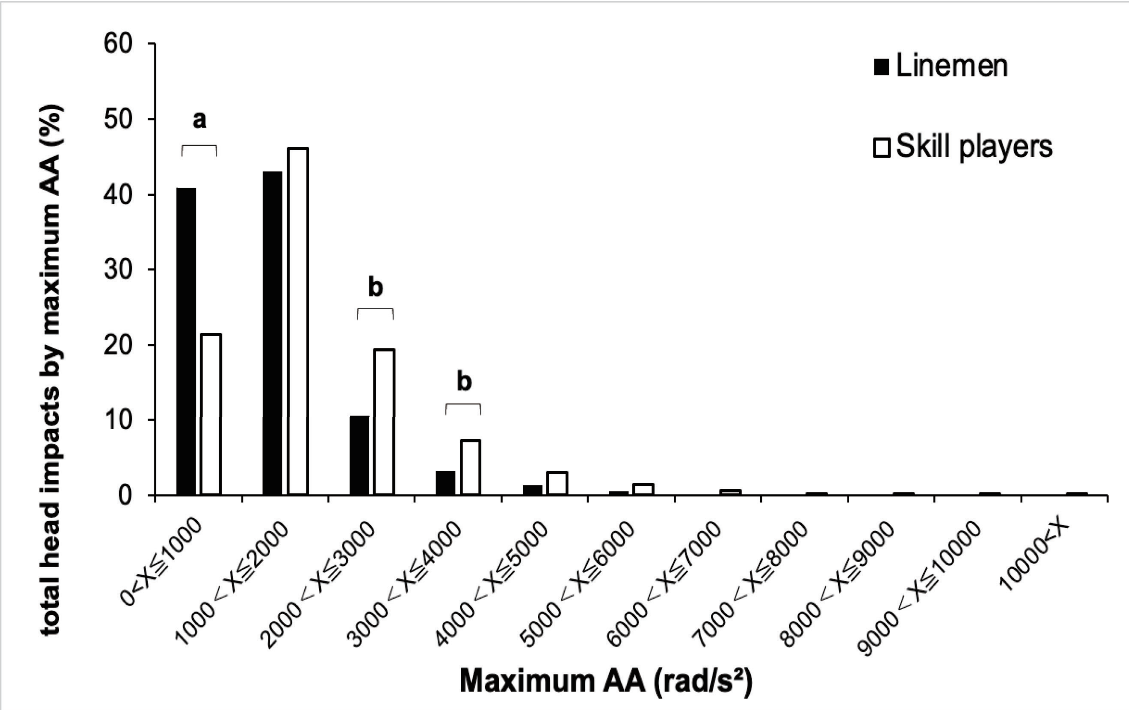

Figure 4. Position-related difference in the percentage of total head impacts by maximum AA.

Saaya Umeoka, Figure 4.

Table 1. Average curvature distance and the amount of the cervical vertebral translation.

		Average of Curvature Distance(mm)		Average of the amount of the cervical vertebral translation. (mm)	P value
		April 2017	November 2017		
C3	All	2.1 ± 2.3	1.8 ± 2.5	1.5 ± 1.0	0.36
	Linemen	1.9 ± 1.9	1.8 ± 2.7	1.7 ± 0.9	0.89
	Skill players	2.2 ± 2.4	1.8 ± 2.5	1.4 ± 1.1	0.37
C4	All	2.3 ± 2.9	2.6 ± 3.2	1.9 ± 1.5	0.44
	Linemen	1.4 ± 2.6	2.4 ± 3.4	1.8 ± 1.0	0.18
	Skill players	2.6 ± 3.0	2.7 ± 3.2	2.0 ± 1.6	0.80
C5	All	2.5 ± 2.9	2.5 ± 3.2	2.0 ± 1.5	0.88
	Linemen	0.7 ± 2.6	1.1 ± 3.5	1.3 ± 0.7	0.50
	Skill players	3.0 ± 2.8	2.9 ± 3.1	2.3 ± 1.6	1.00
C6	All	2.3 ± 2.0	2.2 ± 2.5	1.3 ± 1.1	0.64
	Linemen	1.2 ± 2.2	1.0 ± 2.2	1.0 ± 1.2	0.69
	Skill players	2.6 ± 1.9	2.6 ± 2.5	1.3 ± 1.1	0.71

The curvature distance was calculated as the average length of the hanging line from the baseline. The amount of the cervical vertebral translation was calculated as the absolute value between the average values in April and November.

Table 2. Correlation between the head impact kinematics and the amount of the cervical vertebral translation.

			C3	C4	C5	C6
Total number of head impacts	All	r	−0.10	0.26	−0.14	−0.04
		P value	0.64	0.25	0.54	0.85
	Linemen	r	−0.900 [a]	0.36	−0.30	0.30
		P value	0.04	0.55	0.62	0.62
	Skill players	r	−0.03	0.37	0.13	−0.10
		P value	0.91	0.15	0.63	0.70
Total maximum LA	All	r	−0.07	0.31	−0.10	−0.02
		P value	0.75	0.16	0.66	0.95
	Linemen	r	−0.900 [a]	0.36	−0.30	0.30
		P value	0.04	0.55	0.62	0.62
	Skill players	r	0.30	0.48 [b]	0.22	−0.05
		P value	0.62	0.05	0.39	0.86
Total maximum AA	All	r	−0.03	0.38 [b]	0.01	0.00
		P value	0.90	0.08	0.97	0.99
	Linemen	r	−0.50	−0.05	0.00	0.70
		P value	0.39	0.93	1.00	0.19
	Skill players	r	0.04	0.49 [a]	0.21	−0.07
		P value	0.88	0.04	0.41	0.79

[a] Significant correlations for each measure ($P < .05$). [b] Trends in significant correlations for each measure ($P < .10$).