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Frequency and Magnitude of Head Accelerations in a Canadian Interuniversity Sport Football Team's Training Camp and Season

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The increased awareness of concussion in sport has led to an examination of head impacts and the associated biomechanics that occur during these sporting events. The high rate of concussions in football makes it particularly relevant.[1] The purpose of this study was to examine how frequently, and to what magnitude, Canadian University football players get hit in training camp and how this compares to practices and games in regular season. An ANOVA with repeated measures indicated that, on average, players were hit significantly more in games (45.2 hits) than training camp sessions (17.7 hits) and practices (8.0 hits), while training camp was associated with significantly more hits than practices ($p < .001$, $\eta^2 = .392$). Multiple positional differences were found. In particular, significantly more hits were experienced by offensive linemen (36.7 hits) and defensive linemen (31.6 hits) compared with all other positions ($p < .001$, $\eta^2 = .247$). Study outcomes determined players/positions most at risk for concussion due to head impacts, which is beneficial in forming concussion prevention and assessment strategies. **Key Words:** mTBI, concussion, biomechanics, sport

Key Points

- Canadian Interuniversity Sport football games resulted in larger magnitude and frequency of impacts than both training camp and practices.
- Offensive and defensive linemen received significantly more hits than all other positions.

At the third International Conference on Concussion in Sport, the term concussion was defined to differentiate it from mild traumatic brain injury. The Concussion in Sport Group defined a concussion as an injury that is caused by biomechanical forces that are transmitted to the head or neck resulting in a pathophysiological process affecting the brain. Most sport-related concussions have minor symptoms and 80% of cases are resolved within three weeks.[2,3] However, for the other 20%, symptoms may persist for months or even years.[4]

The rate of concussions is difficult to estimate because many concussions go undiagnosed due to various reasons. In 2009, the United States Center for Disease Control and Prevention estimated that 248,418 emergency room visits were due to concussions caused in sport and recreation.[5,6] In the same year (2009) 133,000 emergency room visits in Ontario, Canada were due to traumatic brain injuries, of which 12% were due to sport.[7] Football, specifically, has a rate of 6.1 concussions per 10,000 athletic exposures.[8] The high prevalence of injury in football creates an ideal setting to better understand the biomechanics of head accelerations and the relationship with concussions. The biomechanical forces can be approximated by measuring the accelerations of the helmet, which securely fits the head.

The number of hits that register meaningful head accelerations (frequency), as well as the precise magnitude of head accelerations, in National Collegiate Athletic Association (NCAA) football has been well documented. Studies at North Carolina,[9] Dartmouth College, Brown University, and Virginia Tech[10–12] have investigated frequency, location, and magnitude of head accelerations associated with different playing positions as well as the differences between practices and games. Only recently has research been conducted to investigate the head accelerations resulting from hits in Canadian Interuniversity Sport (CIS) football.[13] Hits that lead to meaningful head accelerations are a common occurrence of every football player's experience during training camp; however, this type of training session has yet to be investigated in NCAA or CIS settings. Thus, the purpose of the current study was to investigate the frequency and magnitude of head accelerations in a CIS football team's training camp and to compare the data with head accelerations during games and in-season practices. It was hypothesized that training camp would be associated with significantly higher acceleration magnitudes as well as significantly more impacts per session compared with normal season sessions (practices and games). This was hypothesized based on the assumptions that players would be in peak physical fitness during training camp and that the players' intensity levels would be very high given that they are trying to secure a position on the team roster.

Methods

Subjects

Just before the 2014 fall football season, a list indicating the 50 most probable starters was acquired from the coaching staff of a single CIS football team. There is a single level of CIS football, which represents the highest level of nonprofessional football in Canada. Players from that list were invited to participate and 47 volunteered in this observational study. Players were all male and had an average height of 1.86 ± 0.06 m, weight of 107.9 ± 22.5 kg, and an average body mass index (BMI) of 30.7 ± 4.6 kg/m^2. Approval was received from the university research ethics board and players gave informed consent before the beginning of training camp.

Instrumentation

GForce Trackers (GFT) (Artaflex, Markham, Ontario, Canada) are 55-mm long, 29-mm wide, and 14-mm high wireless devices that measure various parameters related to head acceleration. One parameter of interest in this study, referred to as frequency, was the number of hits resulting in linear head accelerations greater than 15g (1g = 9.81 m/s^2). The linear acceleration threshold of 15g was set on the GFTs to be consistent with previous research.[10–13] Once the threshold is met, the GFT records linear acceleration data at 3,000 Hz for the next 40 ms and is time stamped. The second parameter was peak linear head acceleration. GFTs contain a triaxial accelerometer to measure linear acceleration in three directions with a resolution of 1g and are accurate up to 340g according to Artaflex (Markham, Ontario, Canada). The validity and reliability of GFTs have been tested by placing helmets on Hybrid III (HIII) headforms and delivering impacts to the helmet with a linear pneumatic impactor. Data from the GFTs were compared with data from reference accelerometers placed in the HIII. Linear regression analyses indicated that the coefficient of determination for linear acceleration in GFTs ranged from 0.79 to 0.99.[14,15]

Procedures

Upon reception of informed consent, the GFTs were secured inside each football helmet, to the right side of the crown, with an industrial strength fastener (3MTM Dual LockTM Recloseable Fastener SJ3551400 Black, 3M Global Headquarters, St. Paul, MN, USA). The GFTs were consistently placed to the right of the crown next to the padding. Once inserted into the helmet, a GFT was calibrated according to the manufacturer's guidelines, which included connecting the GFT, running the built-in calibration procedure, and choosing the appropriate option for the location of the GFT.

Before all sessions, the head researcher, who was trained by Artaflex in the setup and use of GFTs, would ensure all devices were turned on. During the sessions, if any helmet recorded data while the helmet was not on a player's head, the data were later removed from the sample. For example, if a player threw his helmet, the time and date were recorded.

Data Analysis

The data were distilled to give a frequency count as well as the highest peak acceleration, for each session, for each participant. Frequency and maximum linear acceleration values were combined into a single file and categorized by session type and player position using Microsoft Excel (Microsoft, Redmond, WA, USA). The study design consisted of two dependent variables: frequency and peak acceleration. For each dependent variable, a 3 × 6 (session × position) ANOVA, with repeated measures on the first factor, was conducted using the software package SPSS v22 (IBM Corp., Armonk, NY, USA) to assess for statistical differences. The Holm-Sidak step down multiple comparison procedure, explained by Ludbrook,[16] was used to maintain a type I error value of α = .05. Effect sizes (η^2) were also calculated for each statistical test. According to Cohen, small, medium, and large effect size values for η^2 are 0.10, 0.25, and 0.40, respectively.[17]

Results

In total, 20,950 hits were recorded during the study, accumulating from 10 training camp sessions (5,473 hits), 32 in-season practices (6,293 hits), and 10 games (9,184 hits). Unless otherwise noted, dependent variables are reported as mean ± *SD*. With respect to number of hits, there was no significant session × position interaction (F [7.2, 223] = 1.9, p = .071, η^2 = .0.57). However, the main effect for session indicated that players were hit significantly more in games ($\bar{x}$ = 45.2 ± 34.7 hits) than training camp sessions ($\bar{x}$ = 17.7 ± 18.2 hits) and practices ($\bar{x}$ = 8.0 ± 12.6 hits), while training camp was associated with significantly more hits than practice (F [1.4, 223] = 100.1, p < .001, η^2 = .392) (Figure 1).

The main effect for position indicated that the offensive linemen (OL) ($\bar{x}$ = 36.7 ± 24.6 hits) and the defensive linemen (DL) ($\bar{x}$ = 31.6 ± 25.3 hits) were hit significantly more often than linebackers (LB) ($\bar{x}$ = 21.0 ± 11.2 hits), wide receivers (WR) ($\bar{x}$ = 19.0 ± 14.8 hits), running backs (RB) ($\bar{x}$ = 16.9 ± 11.6 hits), and defensive backs (DB) ($\bar{x}$ = 16.5 ± 17.3 hits) (F [5,155] = 10.2, p < .001, η^2 = .247). Overall, OL and DL were hit significantly more than any other position (Figure 2).

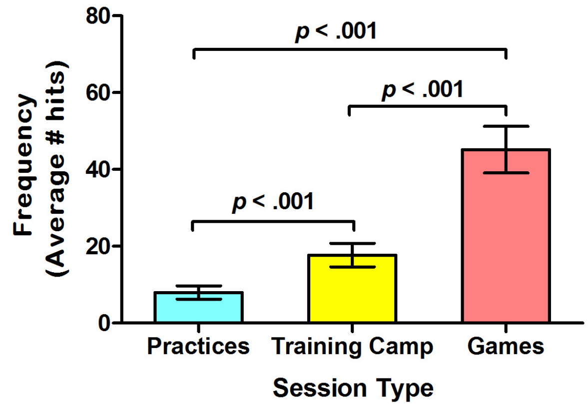

Figure 1 Average number of hits per session per player. A hit was registered by the accelerometer software if the peak linear acceleration for that impact exceeded 15*g*. Error bars represent 95% within-subject confidence intervals.

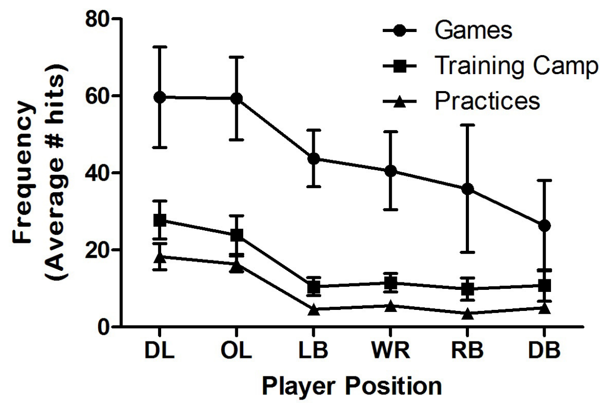

Figure 2 Interaction of player position and session type for average number of hits per session per player (defensive line = DL, offensive line = OL, linebacker = LB, wide receiver = WR, running backs = RB, defensive backs = DB). Error bars represent 95% confidence intervals.

With respect to max linear head acceleration, there was a significant session × position interaction (F [5,155] = 2.6, p = .028, η^2 = .077). The interaction was expanded upon by analyzing each session type individually using one-way ANOVAs. In games, LBs ($\bar{x}$ = 132.4 ± 41.1 *g*) experienced the largest average maximum linear acceleration, which was significantly greater than DL ($\bar{x}$ = 86.1 ± 27.0 *g*), OL ($\bar{x}$ = 97.1 ± 51.8 *g*), and DB ($\bar{x}$ = 87.6 ± 52.5 *g*) ($p \leq .001$) (Figure 3). Interestingly, in training camp, LB ($\bar{x}$ = 65.9 ± 39.3 *g*) was not significantly different from any other position and, in fact, had lower linear accelerations than DL ($\bar{x}$ = 77.8 ± 30.9 *g*), OL ($\bar{x}$ = 67.4 ± 29.7 *g*), RB ($\bar{x}$ = 67.4 ± 31.1 *g*), and WR ($\bar{x}$ = 68.0 ± 41.3 *g*). The only position that received smaller linear accelerations than LB was DB ($\bar{x}$ = 53.7 ± 27.05 *g*), which was significantly less than DL (p < .001) (Figure

3). Furthermore, in practices, DL experienced significantly larger linear accelerations ($\bar{x}$ = 57.3 ± 24.8 g) than LB ($\bar{x}$ = 46.3 ± 24.6 g; p < .008), RB ($\bar{x}$ = 39.4 ± 27.1 g; p < .006), WR ($\bar{x}$ = 47.7 ± 28.3 g; p < .024), and DB ($\bar{x}$ = 43 ± 21.7 g; p < .002). OL ($\bar{x}$ = 56 ± 24.2 g) was not significantly different from DL (p = .701) or WR (p = .066), but was greater than LB (p < .021), RB (p < .013), and DB (p < .004) (Figure 3).

There was a significant main effect for position (F [5,155] = 2.4, p < .042, η^2 = .07). The accompanying pair-wise comparison indicated that this was because LB ($\bar{x}$ = 85.0 ± 4.78 g) experienced significantly larger linear accelerations relative to DB ($\bar{x}$ = 64.5 ± 5.2 g, p < .021) (Figure 4).

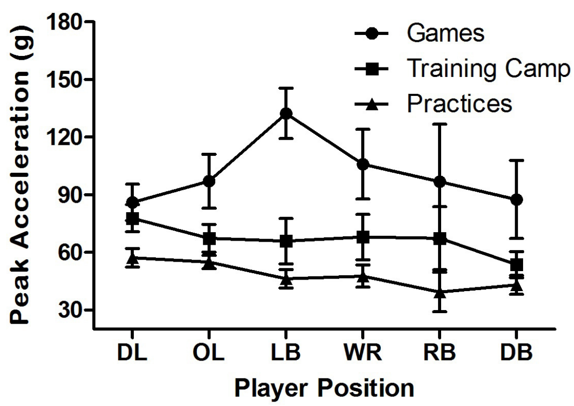

Figure 3 Average peak linear acceleration for each position in each session type (defensive line = DL, offensive line = OL, linebacker = LB, wide receiver = WR, running backs = RB, defensive backs = DB). Error bars represent 95% confidence intervals.

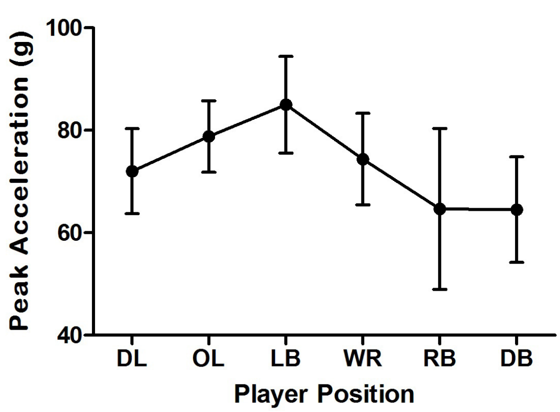

Figure 4 Average peak linear acceleration averaged across all session types (defensive line = DL, offensive line = OL, linebacker = LB, wide receiver = WR, running backs = RB, defensive backs = DB). Error bars represent 95% confidence intervals.

The main effect for session indicated that the average max linear head acceleration of the players was significantly greater in games ($\bar{x}$ = 100.2 ± 49.1 g) than it was in either training camp sessions ($\bar{x}$ = 71.2 ± 33.8 g) or practices ($\bar{x}$ = 48.4 ± 25.4 g). On average, the impacts in training camp were associated with significantly greater max linear accelerations than impacts during in-season practices (F [1.8, 277] = 69.6, p < .001, η^2 = .310) (Figure 5).

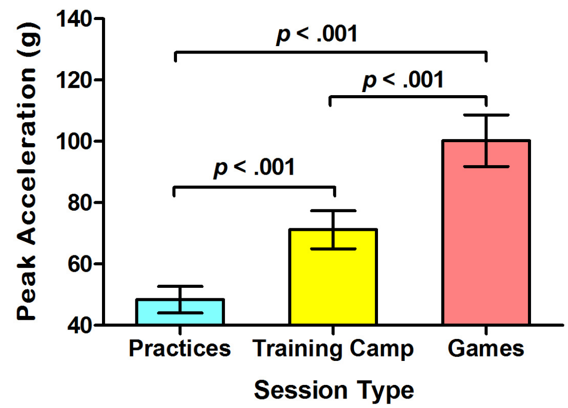

Figure 5 Average peak linear acceleration for each session type. Error bars represent 95% within-subject confidence intervals.

Discussion

The purpose of the current study was to investigate the magnitude and frequency of head accelerations associated with a football training camp in comparison with in-season practices and games. The hypothesis that training camp would be associated with the largest magnitude and frequency of impacts was not supported. Games had significantly larger magnitude and frequency of impacts compared with training camp and practices (Figure 1, Figure 5). However, the magnitude and frequency of impacts associated with training camp were significantly greater than practices (Figure 1, Figure 5).

The data suggests that during games LB experienced the largest max linear accelerations (Figure 4). A previous American study determined that RB and LB experienced the largest linear accelerations of all positions.[12] The fact that RB may not be undergoing large linear accelerations similar to LB in CIS football can potentially be attributed to various factors, one of which is closing distance. Closing distance is the distance between a defender and an attacker and it has been demonstrated that closing distances greater than 10 yards result in significantly larger linear accelerations.[18] Due to the extra player on the field in CIS football, running plays are less likely to have closing distances greater than 10 yards.

OL and DL positions had the highest frequency of impacts across all three session types (Figure 2). This is consistent with previous research where the DL (22%) and the OL (35.5%) combined for 57.5% of all impacts recorded in a study.[9] Similar results have been presented from a study conducted in the United States in which OL, DL, and LB were attributed with significantly more impacts than all other positions.[11] However, this study was performed under NCAA football rules, which are associated with more running plays.[13] Because of the increased running plays, LB would have been relied upon to stop RB at an increased rate compared with the current study performed under CIS football regulations.

These findings provide information valuable to those involved in competitive football. Coaches may consider the results when creating practice plans and training camp schedules to further reduce the number and severity of impacts, with a particular focus on the OL and DL positions, which were found to have elevated frequency of impacts in this study. Medical staff, such as physicians, athletic therapists, and physiotherapists could also benefit from the applicability of the findings. The results suggest that sideline staff could pay particular attention to athletes playing certain positions (OL, DL, and LB) for signs of potential concussions during games because of the higher number or magnitude of hits received. Before games, concussion prevention and education interventions may be focused toward players in these positions to help reduce concussion rates.

Limitations

It is important to note that the current study focused on frequency of impacts per session; however, training camp sessions often occurred two or even three times a day. Therefore, it could be assumed that the number of impacts players received in one day of training camp may be similar to the number of impacts in one regular season game. Many researchers believe angular acceleration is the primary cause of concussions.[19] However, a study compiling 161,732 head accelerations resulting in 105 concussions from various studies determined that, in general, kinematic measures of head accelerations sustained on days of diagnosed concussions were higher than on days without diagnosis. Furthermore, all kinematic measures associated with injury, except angular acceleration, were significantly higher for immediate diagnosis in comparison with delayed diagnosis. Compared with all measurements, linear accelerations proved to be most sensitive toward immediate diagnosis.[20] This supports the use of maximum linear acceleration as a chosen parameter in this study. Another potential limitation is the generalizability between CIS and NCAA football. Three rule differences, in particular, make a generalization challenging. The first rule difference is the number of downs. Teams have four downs (attempts) to gain 10 yards in NCAA, compared with only three downs in CIS. Not only do CIS rules provide fewer opportunities for the offense to gain distance, but the field is also larger: 450 ft. long and 195 ft. wide compared with the NCAA field, which is 360 ft. long by 160 ft. wide. CIS teams also have one extra player on the field (n = 12) when compared with the NCAA (n = 11). Because of the larger field with less chances to gain distance, it is generally agreed that passing plays are implemented more in Canadian football than in American football.[13] In addition, although a large amounts of impacts were measured (20,950), the data were limited to one team and one season; therefore, coaching strategy, play selection, practice plans, and training camp plans could have an influence on the tested variables.

Future studies should consider collecting data from multiple teams across multiple seasons to further our understanding of head accelerations in training camps in both NCAA and CIS football and how these leagues compare. Studies examining the relationship of impact frequency, magnitude, and onset of concussions would be very useful to create a threshold and thus provide better monitoring of players' wellbeing in the future.

Conclusion

In conclusion, the current study examined impact frequency and max linear accelerations of the head associated with games, in-season practices, and training camp sessions in a CIS football team. Data from 20,950 impacts revealed that games were associated with significantly larger magnitudes and frequencies than either training camp or practices, but that training camp was associated with significantly greater magnitudes and frequencies than in-season practices. In addition, positional differences existed; OL and DL positions received more hits in all session types, while LB receive the hardest hits in games. Study outcomes may be beneficial for the development and implementation of concussion prevention and detection strategies.

References

1. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42(2):311–319. PubMed
2. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on Concussion in Sport–the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *South African J Sports Med*. 2009;21(2). doi:10.17159/2413-3108/2009/v21i2a296
3. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on Concussion in Sport: The 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med*. 2013;47(5):250–258. PubMed doi:10.1136/bjsports-2013-092313
4. Rowson S, Brolinson G, Goforth M, Dietter D, Duma S. Linear and angular head acceleration measurements in collegiate football. *J Biomech Eng*. 2009;131(6):061016. PubMed doi:10.1115/1.3130454
5. Clay MB, Glover KL, Lowe DT. Epidemiology of concussion in sport: A literature review. *J Chiropr Med*. 2013;12(4):230–251. PubMed doi:10.1016/j.jcm.2012.11.005
6. Gilchrist J, Thomas K, Xu L, McGuire L, Coronado V. Nonfatal sports and recreation related traumatic brain injuries among children and adolescents treated in emergency departments in the United States, 2001-2009. *MMWR*. 2011;60(39):1337–1342. PubMed
7. Fu TS, Jing R, McFaull SR, Cusimano MD. Health & economic burden of traumatic brain injury in the emergency department. *Can J Neurol Sci*. 2016;43(2):238–247. PubMed doi:10.1017/cjn.2015.320
8. Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD. Concussions among United States high school and collegiate athletes. *J Athl Train*. 2007;42(4):495–503. PubMed
9. Mihalik JP, Bell DR, Marshall SW, Guskiewicz KM. Measurement of head impacts in collegiate football players: An investigation of positional and event-type differences. *Neurosurgery*. 2007;61(6):1229–1235, discussion 1235. PubMed doi:10.1227/01.neu.0000306101.83882.c8
10. Crisco JJ, Fiore R, Beckwith JG, et al. Frequency and location of head impact exposures in individual collegiate football players. *J Athl Train*. 2010;45(6):549–559. PubMed doi:10.4085/1062-6050-45.6.549
11. Crisco JJ, Wilcox BJ, Beckwith JG, et al. Head impact exposure in collegiate football players. *J Biomech*. 2011;44(15):2673–2678. PubMed doi:10.1016/j.jbiomech.2011.08.003
12. Crisco JJ, Wilcox BJ, Machan JT, et al. Magnitude of head impact exposures in individual collegiate football players. *J Appl Biomech*. 2012;28(2):174–183. PubMed
13. Campbell K. Quantifying and Comparing the Head Impact Biomechanics of Different Player Positions for Canadian University Football. (2014). Electronic Thesis and Dissertation Repository. Paper 2259. http://ir.lib.uwo.ca/etd/2259
14. Allison MA, Kang YS, Maltese MR, Bolte JH, IV, Arbogast KB. Measurement of hybrid III head impact kinematics using an accelerometer and gyroscope system in ice hockey helmets. *Ann Biomed Eng*. 2015;43(8):1896–1906. PubMed doi:10.1007/s10439-014-1197-z
15. Campbell KR, Warnica MJ, Levine IC, et al. Laboratory evaluation of the gForce Tracker, a head impact kinematic measuring device for use in football helmets. *Ann Biomed Eng*. 2016;44(4):1246–1256. PubMed
16. Ludbrook J. Multiple comparison procedures updated. *Clin Exp Pharmacol Physiol*. 1998;25(12):1032–1037. PubMed doi:10.1111/j.1440-1681.1998.tb02179.x
17. Cohen J. A power primer. *Psychol Bull*. 1992;112(1):155. PubMed doi:10.1037/0033-2909.112.1.155
18. Ocwieja KE, Mihalik JP, Marshall SW, Schmidt JD, Trulock SC, Guskiewicz KM. The effect of play type and collision closing distance on head impact biomechanics. *Ann Biomed Eng*. 2012;40(1):90–96. PubMed doi:10.1007/s10439-011-0401-7
19. King AI, Yang KH, Zhang L, et al. Is head injury caused by linear or angular acceleration? *Proceedings of International Research Conference on the Biomechanics of Impacts*. Lisbon, Portugal: IRCOBI; 2003.
20. Beckwith JG, Greenwald RM, Chu JJ, et al. Timing of concussion diagnosis is related to head impact exposure prior to injury. *Med Sci Sports Exerc*. 2013;45(4):747–754. PubMed doi:10.1249/MSS.0b013e3182793067

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