Biomechanical head impact characteristics during sparring practice sessions in high school taekwondo athletes

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OBJECTIVE The purpose of this study was to monitor head impact magnitude and characteristics, such as impact location and frequency, at high school taekwondo sparring sessions.

METHODS Eight male high school taekwondo athletes participated in this study. The head impact characteristics were recorded by X-Patch, a wireless accelerometer and gyroscope, during 6 taekwondo sparring sessions. The outcome measures were the peak linear acceleration ($g = 9.81 \text{ msec}^2$), peak rotational acceleration, rotational velocity, and Head Injury Criterion.

RESULTS A total of 689 impacts occurred over 6 sessions involving the 8 athletes. There was an average of 24 impacts per 100 minutes, and there were significant differences in the frequency of impacts among both the sessions and individual athletes. In order of frequency, the most commonly hit locations were the side (38.2%), back (35.7%), and front (23.8%) of the head.

CONCLUSIONS The data indicate that there is a relatively high number of head impacts experienced by taekwondo athletes during sparring practice. According to the rotational acceleration predicting impact severity published in previous research, 17.1% of the impacts were deemed to be a moderate and 15.5% were deemed to be severe.

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KEY WORDS biomechanics; injury and prevention; acceleration; trauma

TAEKWONDO has been an official Olympic combat sport since 2000 and is well known for its full contact and dynamic kicks. With its most popular scoring kick, the turning kick (i.e., roundhouse kick) eliciting an estimated force over 6000 N,¹⁸ it is not surprising that high injury rates and severe injuries during competition have been reported since 1986.²³ Furthermore, since the International Olympic Committee (IOC) reported during the last Summer Olympic Games in London (2012) that taekwondo had the highest number of injuries,² with the second highest number of injuries reported during the Olympic Games in Beijing (2008),⁸ injuries in taekwondo have been under investigation by various research groups.^{14,21} Pieter et al.²¹ reported that the incidence of concussion in taekwondo is approximately 4 times higher than that in American football, with a rate of 19.3 (95% CI

7.1–11.7) compared with 2.3 (95% CI 2.2–2.4) per 1000 athlete exposures, respectively.

In addition to epidemiological studies of injuries in taekwondo, laboratory studies using hybrid dummy heads have been used to estimate the head impact magnitude differences between various taekwondo kicks according to sex, age, height, weight, and skill level.^{4,17} High magnitudes of head linear acceleration have been recorded by the turning kick ($130 \pm 51g$) followed by the jump spinning hook kick ($98 \pm 27g$) and jump back kick ($83 \pm 57g$). Moreover, the turning kick has been reported to produce high Head Injury Criterion (HIC) values of up to 1016.⁶ Recently, other groups studying collision sports such as ice hockey,²⁵ American football,¹ and rugby^{9,10} have used wireless sensors to monitor head impact mechanics in both practice and competition environments. An in-depth dis-

ABBREVIATIONS HIC = Head Injury Criterion; PLA = peak linear acceleration; PRA = peak rotational acceleration; PRV = peak rotational velocity.

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cussion of the various modes for collecting biomechanical head impact data in sport is provided by Guskiewicz and Mihalik.⁷ However, to date there is no known real-time study of head impact biomechanics from taekwondo sparring practices or competitions.

In 2012, the protective quality (i.e., shock attenuation) of World Taekwondo Federation–approved and Korean Taekwondo Association–approved headgear was examined. All of the 5 brands tested failed to reduce a head form's linear acceleration below either 50g for low-impact energy testing (56 J) or below 150g for high-impact energy testing (144 J).^{19,20} As these headgear impact levels were developed based on laboratory studies,¹⁶ it is difficult to state if these testing levels are representative of what actually happens in either practice or competition scenarios. Furthermore, current headgear and helmet impact testing standards by American Standards for Testing and Materials International, National Operating Committee on Standards for Athletic Equipment, and Snell Laboratories only include linear acceleration as a means to evaluate the protective quality of headgear. Therefore, the purpose of the present study was to investigate head impact magnitudes in terms of linear acceleration, rotational acceleration, rotational velocity, head injury criterion values, and impact location during high school taekwondo sparring practice.

Methods

A convenience sample of an elite high school taekwondo team was recruited to participate in this study, as the availability to use a large inventory of sensors was limited. A total of 8 male athletes (mean age [$\pm$ SD] 17 ± 1 years, weight 66.3 ± 8.3 kg, and height 1.73 ± 0.06 m) were randomly selected from the team spanning all competitive weight divisions available. The mean duration of their taekwondo experience was 6.3 ± 2.1 years, and the mean number of years they had competed for a high school team was 2 ± 1.2 years. Because the athletes practiced sparring on Wednesday and Friday from 3 to 5 PM, these were the sessions chosen for data collection. Data were collected for a total of 3 weeks during a period of the season leading up to major national competitions. The IRB of Pusan National University approved this study according to the Helsinki Accord. As the athletes were younger than 18 years, both the athletes and either one of their parents or a legal guardian read and signed a consent form to approve their participation in this study.

After first preparing the skin, by wiping any excess oil/sweat using a cotton alcohol wipe, each athlete had an X-Patch (X2 Biosystems Inc.) attached behind his ear to the mastoid process (Fig. 1) prior to participating in training. The X-Patch is a high-gravity triaxial accelerometer with a 400g maximum per axis and a triaxial angular rate gyroscope with a maximum of 2000 degrees/sec per rotational axis. It records the head linear acceleration ($1g = 9.81 \text{ m/sec}^2$), rotational velocity (rad/sec, when 1 rad is 57.2 degrees), rotational acceleration (rad/sec²), impact location (front, side, back, top), and impact duration at 1000 Hz (Fig. 2). It must be noted that the X-Patch has been demonstrated (Wu et al.²⁶) to overpredict with 120% normalized root square error for the linear acceleration ($15g \pm 7g$) and

FIG. 1. X-Patch sensor fixed behind the ear. The X-Patch provides in vivo impact data such as magnitude, location, and number of impacts. Data are uploaded via a USB connection to a personal computer after a session of data collection/impact monitoring.

290% normalized root square error for the rotational acceleration ($2500 \pm 1200 \text{ rad/sec}^2$). However, Nevins et al.¹⁷ have reported that the X-Patch underestimated rotational acceleration by more than 25%. More importantly, they reported statistically significant correlations (linear $r = 0.44$, $p < 0.001$; rotational $r = 0.15$, $p < 0.001$) between the head impact telemetry system and the X-Patch.

All data were stored locally within the X-Patch and then uploaded to the X2 Biosystems Injury Management Software (X2 Biosystems Inc.). Impact data were then exported to Microsoft Excel. Impacts were identified as any linear acceleration above 10g measured by the X-Patch, which was a limit selected based on a previous studies^{9,10,13} that used the X-Patch. Data were also filtered according to the time that the athletes started and finished their actual sparring practice. The only data included in the analysis were those collected during the sparring practice and not during the warm-up exercises and cool down. All head accelerations above the 10g threshold were included even if a player did not receive a direct blow/kick to his head. SPSS (Windows version 21.0) was used to assess descriptive statistics; data are presented as the mean, SDs, and 95% CIs per athlete and per data collection session.

Results

A total of 689 impacts were recorded from the 8 athletes in 6 sessions of sparring practice. The approximate total exposure time was 2880 minutes of exposure, averaging out at 24 impacts per 100 minutes. Descriptive data per session and per athlete are shown in the corresponding Tables 1 and 2. There were 600 impacts (87.1%) ranging

FIG. 2. Examples of the impact locations for one athlete during one session from the Impact Management System (X2 Biosystems Inc.)—front, back, top, left, and right views. Figure is available in color online only.

between 10g and 39g, 66 (9.6%) ranging between 40g and 69g, and 23 (3.3%) above 70g. There were 461 impacts (66.9%) less than 4600 rad/sec², 121 (17.1%) between 4600 and 7900 rad/sec², and 107 (15.5%) greater than 7900 rad/sec². As for the distribution of the location of impact, there were 246 impacts (35.7%) to the back, 164 (23.8%) to the front, 263 (38.2%) to the side, and 16 (2.3%) to the top of the head. For further analysis a nonparametric Kruskal-Wallis independent-samples test was applied to investigate if there were any significant differences among the sessions and among the individual athletes. The dependent variables peak linear acceleration (PLA), peak rotational acceleration (PRA), peak rotational velocity (PRV), and HIC were all significantly different ($p < 0.05$) between each of the individual sessions ($H(5) = 19.2$, $\eta^2 = 3.8$; $H(5) = 12.2$, $\eta^2 = 2.4$; $H(5) = 23.9$, $\eta^2 = 4.6$; and $H(5) = 12.3$, $\eta^2 = 2.5$, respectively). Similarly, among the impacts received by the athletes, there were significant differences for PRA, PRV, and HIC ($p < 0.05$) between the ($H(7) = 47.2$, $\eta^2 = 6.7$; $H(7) = 31.2$, $\eta^2 = 4.5$; $H(7) = 23.1$, $\eta^2 = 3.3$). The effect size (η^2) demonstrates that the differences between the various training sessions and individual athletes are very large and thus meaningful.

Discussion

Stojisih et al.²⁴ conducted a study similar to ours but among elite boxers who wore accelerometer-instrumented headgear used to monitor head impact kinematics during a sparring session. To our knowledge, our study may be the first of its kind in which head impacts from martial arts kicks were assessed. An important difference in our study in contrast to the boxing study²⁴ was the primary objec-

tive of assessing the effect of head impacts on cognitive performance in boxers, with our aim to provide a basis for biomechanical impact characteristics from taekwondo kicks during sparring practice. As our data were the result of 6 sparring sessions from a much smaller group of athletes than was assessed in the boxing study, the volume of impacts was much lower, although the biomechanical data were similar in magnitude (male boxers: PLA 30 ± 21 g, PRV 2571 ± 1852 rad/sec, and HIC 43 ± 100 ; vs male taekwondo athletes: PLA 24 ± 22 g, PRV 4455 ± 3516 rad/sec, and HIC 35 ± 130). Although not statistically compared, the rotational acceleration derived from our data appears to be higher (nearly 2-fold greater) when considering the point estimates for the taekwondo high schoolers: 4455 rad/sec² (95% CI 4192–4718 rad/sec²) versus 2571 ± 1856 rad/sec² for male boxers and 2533 ± 1524 rad/sec² for female boxers.²³ This observation may be reason to further evaluate the effect of kicks on head rotational acceleration, as this kinematic characteristic may be different when compared with other sports.

Although it is known that head injuries like concussions result from a variety of forces (e.g., combination of linear acceleration, rotational acceleration, location of impact, and number of blows) and likely not purely one factor (e.g., rotational acceleration alone), recent analyses point out that linear acceleration was not significantly different than a combined probability of concussion²² and that it may hold similar utility as a predictor of concussion. Although the linear acceleration results observed in our study do not fall within the top 50% of subconcussive impacts,²² our mean rotational acceleration data fell within the level of impact ($4726 + 1931$ rad/sec²) involved in concussive impacts (62,974 impacts with 37 concussions) analyzed by

TABLE 1. Descriptive statistics per session for the linear acceleration, rotational acceleration, rotational velocity, and HIC

Variable/ Session No.	No.	Mean	SD	95% CI		Max
				Lower	Upper	
Linear acceleration (g)						
1	60	22	12	19	25	49
2	114	25	24	20	29	234
3	148	27	23	23	30	152
4	124	23	23	19	28	195
5	152	21	20	18	24	169
6	91	24	24	20	29	163
Total	689	24	22	22	25	234
Rotational accelera- tion (rad/sec ²)						
1	60	4273	3020	3492	5053	14,093
2	114	4652	3449	4012	5292	15,403
3	148	5148	3980	4501	5794	22,561
4	124	4320	3365	3722	4918	16,651
5	152	3904	3308	3374	4435	19,278
6	91	4305	3529	3570	5040	19,002
Total	689	4455	3516	4192	4718	22,561
Rotational velocity (rad/sec)						
1	60	21	12	18	24	49
2	114	23	14	20	25	57
3	148	24	14	22	26	57
4	124	20	14	18	23	57
5	152	18	13	16	20	57
6	91	22	13	19	25	57
Total	689	21	14	20	22	57
HIC						
1	60	20	32	11	28	164
2	114	41	176	8	74	1827
3	148	40	116	21	59	979
4	124	38	145	13	64	1313
5	152	23	75	11	35	706
6	91	45	171	10	81	1234
Total	689	35	130	25	45	1827

TABLE 2. Descriptive statistics per athlete for linear acceleration, rotational acceleration, rotational velocity, and HIC

Variable/ Athlete No.	No.	Mean	SD	95% CI		Max
				Lower	Upper	
Linear acceleration (g)						
1	228	27	27	24	31	234
2	62	25	29	17	32	195
3	84	19	10	17	22	53
4	57	19	10	16	21	56
5	78	19	9	17	21	47
6	114	25	18	21	28	120
7	25	38	42	21	55	169
8	41	16	7	14	18	46
Total	689	24	22	22	25	234
Rotational acceleration (rad/sec ²)						
1	228	5363	4066	4832	5893	19,852
2	62	3461	2970	2707	4215	16,651
3	84	4142	2449	3610	4674	11,385
4	57	3141	2175	2564	3718	11,039
5	78	3551	2257	3042	4059	9986
6	114	5147	4087	4389	5906	22,561
7	25	5177	4221	3434	6919	14,704
8	41	2734	1838	2154	3314	9384
Total	689	4455	3516	4192	4718	22,561
Rotational velocity (rad/sec)						
1	228	25	16	23	27	57
2	62	18	11	15	20	57
3	84	20	10	18	22	43
4	57	18	11	15	21	47
5	78	19	11	16	21	45
6	114	22	14	19	25	56
7	25	26	19	18	34	57
8	41	14	8	11	17	41
Total	689	21	14	20	22	57
HIC						
1	228	57	184	33	81	1827
2	62	48	196	2	97	1313
3	84	12	20	8	16	102
4	57	10	13	7	14	69
5	78	10	15	7	14	83
6	114	32	67	20	44	471
7	25	84	171	13	154	706
8	41	6	7	4	8	32
Total	689	35	130	25	45	1827

Rowson and Duma.²² Differences must be noted among impacts in taekwondo, boxing, and football because differences in protective helmets, designs, and nature of impacts are present in each and so the data are not directly comparable. With real-time competition data more readily available, these impact levels, along with diagnosed concussions, will either confirm or refute this assertion.

Our study only represents impact characteristics from 6 sparring sessions, and for this reason it is too early to make clear recommendations for policy and/or protective equipment changes. Our data appear to be quite similar to those observed during boxing sparring sessions. Although the genres of these 2 sports are similar, our recent laboratory studies^{5,6,17,20} might direct others to con-

sider that the impact magnitudes are higher in taekwondo (or other kicking-oriented sport) than in boxing.⁴ Again, the infancy of these results and others^{5,18,19,23} do not allow for conclusive remarks, but they do make it reasonable to consider different impact mechanisms in martial arts, and

therefore the exploration of different protective headgear design should be considered within the industry.

The results of the present study, although preliminary and from a small group of volunteers, help piece the puzzle together in understanding the true impact characteristics of head injury in martial arts. Our previous laboratory data obtained from high school taekwondo athletes¹⁷ indicate mean impact magnitudes from the most commonly used kick (i.e., a turning kick) of 58g (95% CI 53g–63g). Only 9.6% of impacts from the current study are within a range of 40g–69g, where over 80% of impacts that we recorded might be termed subconcussive when only considering linear acceleration. When taking into account the rotational accelerations, a greater percentage (17.1% and 15.5%) of the impacts was associated with mild to severe head impacts, respectively.²² However, one should keep in mind that these impact severity scales are based on head impact data²² from college/university-aged American football players and may not be directly comparable to the 15- to 18-year-old males who participated in this study.

With 4% (23 impacts) of impacts from our observations being over 70g and 15.5% (107 impacts) above 7900 rad/sec² from 6 training sessions, the potential for technology like the X-Patch to be used for identifying otherwise undetected concussions may be helpful. Langburt et al.¹² have reported that nearly 47% of surveyed football players potentially underreport concussive events. With a high prevalence of underreporting of concussion in sports like football, using technology such as that which was used in the current study may help identify those injuries that may go otherwise undiagnosed.

The data from this study show a high frequency of the impacts to the side (38.2%) and back (35.7%) of the head. The data are also in agreement with epidemiological findings that indicate the most common kick to cause a head injury is the turning kick, which tends to hit the temporal region or the back of the athletes' head when they are turning to avoid the kick.¹¹ This impact location data can be useful when considering the design of the protective headgear; thicker padding¹⁵ can be added to the side and back of the headgear in an effort to ensure that these locations better mitigate impacts that could otherwise cause severe head injury such as skull fracture. It is important to understand that no evidence to date identifies helmets that can prevent concussion.

This study is limited in 2 main areas. First, high schools in Korea do not currently employ full-time, on-site medical staff (athletic trainers, nurses, etc.), or even part-time medical staff, making post-impact injury diagnosis impossible. Given the issue of underreporting of concussions in sports in general¹² and in taekwondo,³ the environment for this study in Korea is not favorable, yet because sport norms vary from country to country, the environment is vast in terms of data abundance. Second, our data did not include visual observations from sideline video recordings. Although at least one researcher was present at all practices, no mechanism was in place for visual analysis of impacts, which makes confirmation of precisely which technique was responsible for each corresponding impact not possible.

The field data collected in football over many years

have provided great insight into a model of study fitting for the athletic environment. Our investigation truly only scratches the surface of the structural knowledge already set out from these early and recent football studies. Additionally, our small sample of participants restricts our ability to definitively make clear conclusions, as we have highlighted the infancy of data collection in this population to date. Future studies should make efforts for longitudinal data collection with more than one team. Additionally, because the competition arena brings different emotional and behavioral dimensions to the sport, researchers are encouraged to collect data during full-contact competitions. Since data collection in some countries is challenging due to a lack of health service systems (i.e., a sports medicine team made up of sports medicine doctors and athletic trainers) available in the United States and some other countries, an effort to include medical personnel such as athletic trainers to follow up on hits-of-interest may help in identifying potential injuries and providing a greater illustration of the mechanisms of head injury as they appear in martial arts like taekwondo.

Conclusions

Impacts observed over the course of 6 taekwondo training sessions in a small cohort of athletes led us to identify that a majority (approximately 70%) of impacts were of low magnitude for linear and rotational accelerations. Resultant rotational accelerations were of a high magnitude and may represent an area to consider for understanding mechanisms of concussion in martial arts. Most impacts were to the side and back of the head on the order of the following: magnitude of linear acceleration 24 ± 22 g; rotational acceleration 4455 ± 3516 rad/sec²; rotational velocity 21 ± 14 rad/sec; and an HIC of 35 ± 130 . Future work to collect more comprehensive data from different sexes and skill levels will be necessary.

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References

1. Broglio SP, Martini D, Kasper L, Eckner JT, Kutcher JS: Estimation of head impact exposure in high school football: implications for regulating contact practices. **Am J Sports Med** 41:2877–2884, 2013
2. Engebretsen L, Soligard T, Steffen K, Alonso JM, Aubry M, Budgett R, et al: Sports injuries and illnesses during the London Summer Olympic Games 2012. **Br J Sports Med** 47:407–414, 2013
3. Fife GP, Harter RA: A comparison of concussion assessment and management protocols used by medical personnel at elite taekwondo tournaments in the Republic of Korea and the United States. **Arch Budo** 8:1–6, 2012
4. Fife GP, O'Sullivan D, Pieter W: Biomechanics of head injury in Olympic taekwondo and boxing. **Biol Sport** 30:263–268, 2013
5. Fife GP, O'Sullivan DM, Pieter W, Cook DP, Kaminski TW: Effects of Olympic-style taekwondo kicks on an instrumented head-form and resultant injury measures. **Br J Sports Med** 47:1161–1165, 2013

6. Fife GP, O'Sullivan DM, Pieter W, Kaminski TW: Effects of taekwondo kicks on head accelerations and head injury: a pilot study. **Int Sportmed J** 14:53–56, 2013
7. Guskiewicz KM, Mihalik JP: Biomechanics of sport concussion: quest for the elusive injury threshold. **Exerc Sport Sci Rev** 39:4–11, 2011
8. Junge A, Engebretsen L, Mountjoy ML, Alonso JM, Renström PA, Aubry MJ, et al: Sports injuries during the Summer Olympic Games 2008. **Am J Sports Med** 37:2165–2172, 2009
9. King D, Hume PA, Brughelli M, Gissane C: Instrumented mouthguard acceleration analyses for head impacts in amateur rugby union players over a season of matches. **Am J Sports Med** 43:614–624, 2015
10. King DA, Hume PA, Gissane C, Clark TN: Similar head impact acceleration measured using instrumented ear patches in a junior rugby union team during matches in comparison with other sports. **J Neurosurg Pediatr** 18:65–72, 2016
11. Koh JO, Watkinson EJ: Possible concussions following head blows in the 2001 Canadian National Taekwondo Championships. **Crossing Boundaries** 1:1–8, 2002
12. Langburt W, Cohen B, Akhthar N, O'Neill K, Lee JC: Incidence of concussion in high school football players of Ohio and Pennsylvania. **J Child Neurol** 16:83–85, 2001
13. Lennon A: **Measurement of Head Impact Biomechanics: A Comparison of the Head Impact Telemetry System and X2Biosystems XPatch [master's thesis]**. Chapel Hill, NC: University of North Carolina, 2015
14. Lystad RP, Swain MS, Graham PL: Risk factors for injury in Olympic-style competition taekwondo: a systematic review. **J Sports Med Phys Fitness** 53:655–664, 2013
15. McIntosh AS, McCrory P: Impact energy attenuation performance of football headgear. **Br J Sports Med** 34:337–341, 2000
16. Moffitt M: **Response of Martial Arts Headgear to Simulated Kicks [master's thesis]**. Berkeley, CA: University of California, Berkeley, 1995
17. Nevins D, Smith L, Kensrud J: Laboratory evaluation of wireless head impact sensor. **Procedia Eng** 112:175–179, 2015
18. O'Sullivan D, Chung C, Lee K, Kim E, Kang S, Kim T, et al: Measurement and comparison of taekwondo and yongmudo turning kick impact force for two target heights. **J Sports Sci Med** 8 (CSSI3):13–16, 2009
19. O'Sullivan DM, Fife GP: Impact attenuation of protective boxing and taekwondo headgear. **Eur J Sport Sci** 16:1219–1225, 2016
20. O'Sullivan DM, Fife GP, Pieter W, Shin I: Safety performance evaluation of taekwondo headgear. **Br J Sports Med** 47:447–451, 2013
21. Pieter W, Fife GP, O'Sullivan DM: Competition injuries in taekwondo: a literature review and suggestions for prevention and surveillance. **Br J Sports Med** 46:485–491, 2012
22. Rowson S, Duma SM: Brain injury prediction: assessing the combined probability of concussion using linear and rotational head acceleration. **Ann Biomed Eng** 41:873–882, 2013
23. Siana JE, Borum P, Kryger H: Injuries in taekwondo. **Br J Sports Med** 20:165–166, 1986
24. Stojish S, Boitano M, Wilhelm M, Bir C: A prospective study of punch biomechanics and cognitive function for amateur boxers. **Br J Sports Med** 44:725–730, 2010
25. Wilcox BJ, Machan JT, Beckwith JG, Greenwald RM, Burmeister E, Crisco JJ: Head-impact mechanisms in men's and women's collegiate ice hockey. **J Athl Train** 49:514–520, 2014
26. Wu LC, Nangia V, Bui K, Hammoor B, Kurt M, Hernandez F, et al: In vivo evaluation of wearable head impact sensors. **Ann Biomed Eng** 44:1234–1245, 2016

Disclosures

Both Dr. Fife and Dr. O'Sullivan are members of the World Taekwondo Federation Para-Taekwondo Governing Board and Co-Chairs of the Research and Education Committee.

Author Contributions

Conception and design: both authors. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: both authors. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of both authors: Fife. Statistical analysis: both authors. Administrative/technical/material support: O'Sullivan.

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