原著論文

Quantitative evaluation of trunk acceleration of elementary-school soccer players using grade measured during competitive matches

－ Research into the prevention of growth-related injuries －

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Abstract：The aim of this study was to compare the trunk accelerations that occur during competition in elementary schools football between different grade levels. Sixty-two elementary schools football players (grade 6 : 13, grade 5 : 26, grade 4 : 14, grade 3 : 9) played an 8 vs 8 match with a GPS sensor with a built-in 3-axis accelerometer in the middle of the back. The distance traveled in the match, the distance traveled per height, and the frequency of occurrences of composite accelerations of 4 G, 6 G and 8 G or more were extracted and compared for frequency of occurrence by grade using one-way analysis of variance. The results showed that the distance traveled per minute was significantly higher in grades 5 (100.0 ± 10.6 m/min) and 6 (103.2 ± 9.2 m/min) than in grade 3 (89.9 ± 7.3 m/min), but there was no significant difference in the relative distance traveled divided by height. The difference in the frequency of synthetic acceleration at each of the synthetic acceleration thresholds showed that at 4 G and above, the frequency of synthetic acceleration per minute was significantly higher in grades 5 and below (36.98 ± 10.25 - 38.87 ± 10.14 counts/min) than in grades 6 (20.07 ± 7.71 counts/min), but not in grades 6 and 8 G (20.07 ± 7.71 counts/min). No significant differences were found in the frequency of synthetic accelerations above 6 G and 8 G. The phenomenon of a higher frequency of synthetic acceleration in the fifth and lower grades than in the sixth grade suggests that the phenomenon of high impact susceptibility during football activities is captured, and the data may help to prevent Sever's disease and growth-related disorders, which are more common at around 11 years of age.

Keywords：Wearable sensor,　Accelerometer,　Children,　External load,　Soccer

抄録：本研究は小学生サッカーの競技中に発生する体幹加速度を学年ごとに比較検討することを目的とした．小学生サッカー選手62名（６年生：13人，５年生：26人，４年生：14人，３年生：9名）が背面中央部に３軸加速度計内蔵のGPSセンサを装着し８対８の試合を行った．試合における走行距離，身長当たりにおける走行距離，合成加速度が４G，６Gおよび８G以上となった発生頻度を抽出し，一元配置分散分析を用いて学年ごとにおける発生頻度の比較を行った．その結果，１分間当たりの移動距離は，３年生（89.9±7.3 m/min）に比べて５年生（100.0±10.6 m/min），６年生（103.2±9.2 m/min）は有意に高い値を示したが，身長で除した相対的な移動距離に関しては有意差が認められなかった．また合成加速度各閾値における発生頻度の違いをみてみると，４G以上において，１分間当たりにおける合成加速度の発生頻度は，５年生以下（36.98±10.25～38.87±10.14 counts/min）が６年生（20.07±7.71 counts/min）より有意に高い値を示したが，６Gおよび８G以上の合成加速度発生頻度においては，有意な差は認められなかった．小学５年生以下において小学６年生より合成加速度の発生頻度が多い現象は，サッカー活動中において衝撃を高頻度に受けやすい現象を捉えていることが示唆され，11歳頃から多発するSever病や成長関連障害予防の一助となり得るデータであることが考えられた．

キーワード：ウェアラブルセンサ，加速度，子供，外的負荷，サッカー

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1. Background

Soccer is a high-intensity, high-impact team sport, and carries the risk of injury due to trauma or overuse [1]. Like regular players [2] or top-level athletes [3], most injuries that occur in children playing soccer occur in the lower limbs [4]. Moreover, Osgood–Schlatter disease of the knee and leg overuse-associated conditions are common among child soccer players. Furthermore, chronic bone stress is an outstanding issue in these players. A study targeting soccer players aged 7 – 12 years reported that 16.8 % of the participants exhibited growth-related impairments or overuse symptoms. In other words, the participants demonstrated evidence of repetitive microscopic injuries [4]. A survey on knee and heel pain conducted as a part of a cross-sectional study of soccer players aged 8 – 12 years elicited that 29.4 % and 31.1 % of the players reported pain in the knee and heel, respectively [5]. These findings suggest that prevention of overuse disorders is of critical importance to prevent injuries in children. Overuse disorders are caused by prolonged exposure to stress caused by external loads. Iwame et al [5]. reported that monitoring and controlling training volume is effective in preventing overuse injuries. Furthermore, the triggering mechanisms underlying sports injuries need to be investigated from the perspectives of competitive situations, opponent behavior, and biomechanics [6].

In recent years, research using wearable accelerometers to understand the characteristics of movements during actual competitive matches has been carried out. High-impact movements during basketball, volleyball, and badminton matches have been shown to occur during deceleration while performing on-ball defense [7], one-footed landings after blocking or spiking [8], and landings after overhand strokes [9]. Trunk acceleration data gathered using wearable accelerometers is an objective index for monitoring external load, and is correlated with ground reaction forces [10].

Direct measurements of ground reaction forces or heel loading can be performed in the laboratory, but not during actual football activities. Stress or overloading of the heel is a possible cause of overuse disorders during growth [11]. Repetitive ground reaction forces are thought to be a possible cause of heel pain in youth football players is thought to be than one-off ground reaction forces, which are measured during actual football activities such as matches or practices. Here, we focused on trunk acceleration, which has been shown to be related to ground reaction force in previous studies. Trunk acceleration can be measured during actual sport activities, and it was assumed that measuring it, could quantify the degree of repetitive ground reaction force that may cause heel pain in youth football players.

Therefore, in this study, we aimed to compare trunk acceleration data collected from elementary school soccer players during actual competitive matches. It was hypothesized that the frequency of acceleration decreases with increasing grade level.

2. Methods

Materials

A total of 62 elementary school-age male soccer players (age 10.9 ± 1.0 years, height 141.5 ± 9.4 cm, weight 34.0 ± 7.2 kg). As the school year in Japan starts in April and ends in March, accordingly, children and students born between 2 April and 1 April of the following year are in the same school year. For this reason, in this study, children born between April 2009 - March 2010, April 2010 and March 2011, April 2011 and March 2012, April 2012 and March 2013 were categorized as 'Grade 6', 'Grade 5', 'Grade 4' and 'Grade 3', respectively. All participants were amateur soccer players and belonged to the Japan Junior Sport-Club Association. Only field players were included in this study and goalkeepers were excluded. Players who did not experience any injury in the six months prior to the study were included. All participants and their legal guardians were explained the study objectives and procedures involved in detail, along with any foreseeable risks. Written informed consent was obtained from the guardians of all the participants prior to the commencement of the study. The study was approved by the Ethics Committee of Tokyo Ariake University School of Medicine (approval number 346) and was conducted in accordance with the principles of the Declaration of Helsinki.

Data collection

The anthropometric measurements included height (seca 213), weight (TANITA HD-661) and sitting height of all test subjects. The sitting height was measured as the distance from the floor to the top of the skull on a 30 cm high platform. The sitting height was measured by having the subjects sit on a 30 cm high platform. The leg length was calculated by subtracting the sitting height from the body height.

Prior to data collection, all players performed at least

30 minutes of warm-up drills that included running, stretching, passing, shooting and other elements of basic skill training elements. Measurements were taken from two matches played in a city tournament and were taken during an 8 vs 8 football match (15 mins - 5 mins interval - 15 mins), the data from at least 15 minutes played in one match. The size of the pitch was 68 m × 50 m in accordance with the JFA rules of the game. Coaches were allowed to replace their regular players with substitutes and the average playing time for each player was 38.7 ± 12.5 minutes. The total playing time for all participants was 2402.7 minutes.

Each GPS unit was equipped with a triaxial accelerometer sensor (SPI HPU, GPSPORT, Australia). The sensor was calibrated such that, when each axis direction was aligned with the direction of the gravitational force, the measured acceleration would read 1 G. Sensor axes were calibrated in a manner that the left-right direction was the X-axis, the up-down direction was the Y-axis, and the forward-backward direction was the Z-axis (Figure 1). Participants wore a compression inner layer to prevent body movements and vibrations from dislodging the sensor.

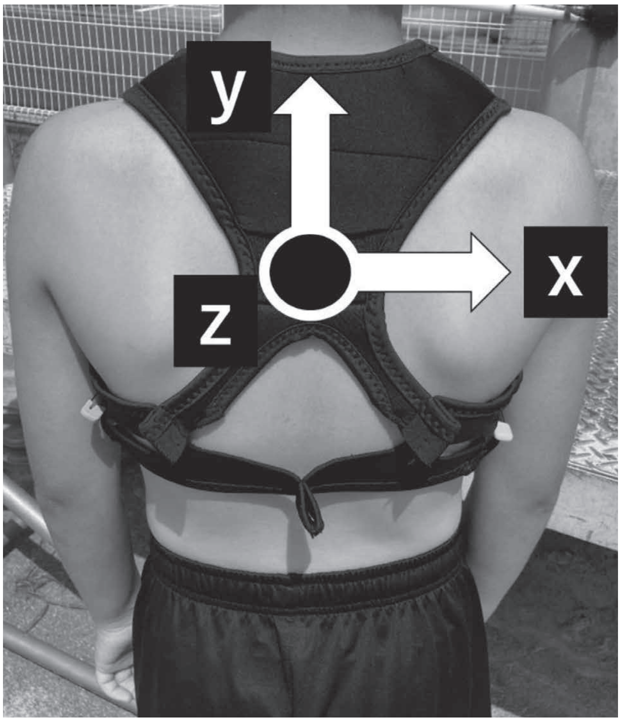

Figure 1. Triaxial accelerometer sensor was placed inside a pocket located in the center of a proprietary vest designed to hold it. Participants wore a compression inner layer above the accelerometer.

Data analysis

Global positioning system (GPS) data was used to determine the total distance traveled by each player during the match. The playing time of each player was then used to calculate the distance traveled per minute (Distance ; m/min). Since the distance traveled is assumed to vary with height, the distance traveled per minute divided by the height of the individual player was calculated as the distance traveled per height (Corrected distance ; m/min/cm).

During measured matches, the triaxial acceleration data collected by the sensor was saved internally. After measurement, a proprietary docking station was used to transfer data via a proprietary software application (Team AMS, GPsports, Australia) from the sensor to a personal computer for long-term storage. Team AMS was used to calculate each acceleration component and the resultant acceleration ($\sqrt{X^2 + Y^2 + Z^2}$) from the stored data. Next, for a given player, the frequency of occurrence of a certain resultant acceleration value (counts/min) was determined by dividing the number of times a certain resultant acceleration value occurred by the total number of times the player played [12]. Resultant acceleration thresholds were set at 4 G, 6 G and 8 G and data processing was performed for each value. A moderate to strong correlation was seen between an increase in blood creatine kinase concentration and an increase in acceleration at the acceleration thresholds used in this study [13]. Blood creatine kinase is considered a marker of muscle damage and can lead to muscle stiffness in the heel, which is directly impacted, leading to Sever's disease-inducing events. In a previous study [14] on 11 elementary schools football players, 6 G and 8 G were used to extract instantaneous high-impact movements for Sever's disease-inducing events, with 6 G often observed during slow-down movements (slowing down slowly) and 8 G during shuffling (adjustment of stride length while slowing down). Koyama et al [13]. reported that synthetic acceleration at 4 G reflected the overall total locomotion, as synthetic acceleration and session RPE at 4 G showed a moderate correlation. Therefore, all three thresholds, as well as the high load threshold, were used to quantitatively evaluate the load in elementary schools football players.

Statistical analysis

All the statistical analyzes were performed using the JMP Pro 17 software. The software was used to calculate a one-way analysis of variance for each parameter by grade. Multiple comparisons were tested using the Tukey–Kramer method. The threshold of significance was set at less than 5 %.

3．Results

In terms of physical characteristics, there were significant differences in height between grades. For weight, the third grade showed significantly lower values than the fifth and sixth grades. For sitting height, significant differences were found in all grades except grades 4 and 5 (Table 1). For leg length, significant differences were found in all grades except grades 5 and 6. For distance traveled per minute, the following were found : 103.2, 100.0, 96.5 and 89.9 m/min for grades 6, 5, 4 and 3, respectively. Fifth- and sixth-grade students showed significantly higher values for distance traveled per minute compared to third-grade students (Table 2). However, no significant differences were found for relative distance traveled (distance traveled per unit time divided by height). Figure 2 - 4 shows the results for acceleration at each grade level. The evaluation of differences in the frequency of occurrence at different threshold values showed that for threshold values ≥4 G, the frequency of synthetic acceleration per minute was significantly higher in grades 5 and below than in grade 6 (Fig. 2). Conversely, no significant differences were found for thresholds ≥6 G and ≥8 G (Fig. 3. 4).

Table 1. Physical characteristics of the study participants by grade

	Grade 3 (N=9)	Grade 4 (N=14)	Grade 5 (N=26)	Grade 6 (N=13)
Age (years)	9.2±0.3[b,c,d]	10.2±0.3[a,c,d]	11.3±0.3[a,b,d]	12.2±0.3[b,c,d]
Height (cm)	129.5±4.7[b,c,d]	138.2±6.4[a,c,d]	144.3±6.5[a,b,d]	150.2±5.1[b,c,d]
Weight (kg)	28.0±4.2[c,d]	33.3±5.9	34.4±6.8[a]	39.3±6.3[a]
Sitting height (cm)	70.8±2.3[b,c,d]	74.8±3.3[a,d]	77.5±3.7[a,d]	80.9±3.7[b,c,d]
Leg length (cm)	58.8±3.0[b,c,d]	63.4±3.2[a,c,d]	66.8±4.0[a,b]	69.3±2.6[b,c]

Note
Mean±SD
a Significantly different from grade 3 ($p < .05$).
b Significantly different from grade 4 ($p < .05$).
c Significantly different from grade 5 ($p < .05$).
d Significantly different from grade 6 ($p < .05$).

Table 2. Distance traveled by the study participants by grade

	Grade 3 (N=9)	Grade 4 (N=14)	Grade 5 (N=26)	Grade 6 (N=13)
Total Game time(min)	340.8	502.2	810.5	749.3
Distance (m/min)	89.9±7.3[c,d]	96.9±8.4	100.0±10.6[a]	103.2±9.2[a]
Corrected distance (m/min/cm)	0.69±1.55	0.70±1.31	0.69±1.63	0.69±1.80

Note
Mean±SD
a Significantly different from grade 3 ($p < .05$).
b Significantly different from grade 4 ($p < .05$).
c Significantly different from grade 5 ($p < .05$).
d Significantly different from grade 6 ($p < .05$).

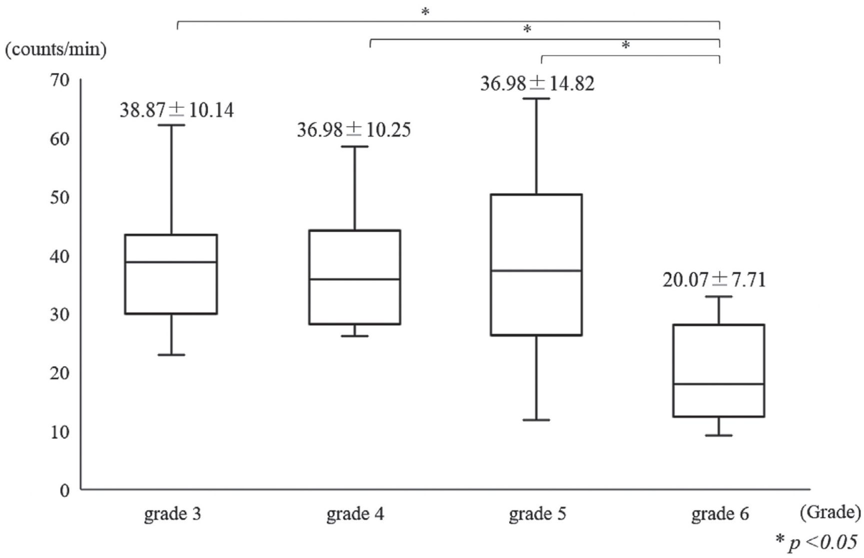

Figure 2. Occurrence frequencies of resultant acceleration values at or above 4 G

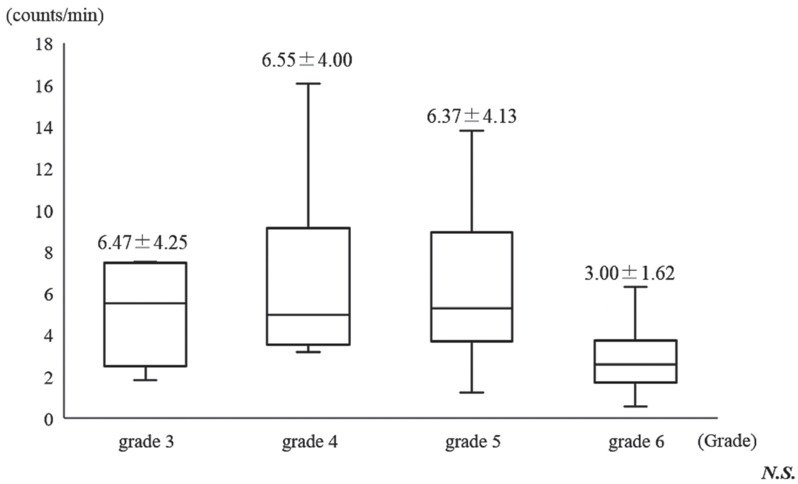

Figure 3 Occurrence frequencies of resultant acceleration values at or above 6 G

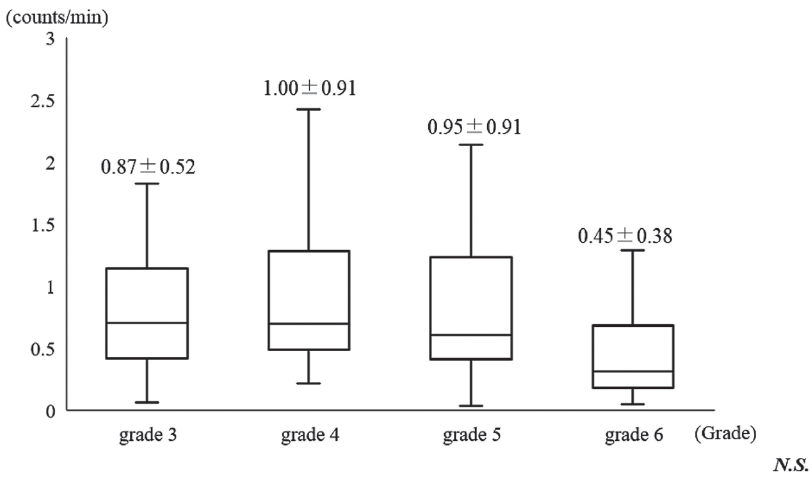

Figure 4. Occurrence frequencies of resultant acceleration values at or above 8 G

4. Discussion

This is the first study to quantitatively assess the trunk acceleration of elementary schools football players during a match by grade level. The results showed that, contrary to the hypothesis, there was no significant difference between grades in the frequency of occurrence of acceleration values above 6 G and 8 G, but there was a hypothesized difference in the frequency of acceleration values above 4 G, with children in grades 5 and below being significantly higher than those in grades 6 and below.

In terms of distance traveled per minute during play time, the values were 103.2, 100.0, 96.9, and 87.2 m/min for sixth, fifth, fourth, and third graders, respectively. Distance traveled per minute increased with increase in grade. However, we considered the fact that height also increased with grade, and after dividing the distance traveled per minute by player height, no significant differences were observed. This suggests that there are no differences in the relative distances traveled by players in their growth phase. It has been suggested that running distances are longer in adult players than in junior players [15], but this is thought to vary depending on the level of the game and the environment [16]. However, the results of this study showed that elementary schools footballers in grades 5 and 6 run longer distances than those in grade 3, but there was no significant difference in distance traveled per height, suggesting that this is not due to the growth process, but changes due to the game environment and other factors. This is considered to be due to changes in the game environment and other factors, rather than due to the growth process.

Looking at the frequency of synthetic acceleration, the results show that the frequency of synthetic acceleration in grades 5 and below was higher than that in grades 6 and above in the frequency of synthetic acceleration at 4 G and above. An acceleration of 1 G refers to a force pushing against the ground with the same force as the earth's gravity (the same as one's body weight). For example, 4 G or 6 G would mean that the body is subjected to a load four or six times greater than its body weight. A study investigating trunk acceleration in other sports, a study of high school female badminton players found that the playing movements that resulted in 4 G or more were underhand stroke and overhand stroke landings on the dominant hand side, and cutting from the step [9]. These are specific high-impact movements that were examined because the risk movement for anterior cruciate ligament injury is a single leg landing. Studies [14] examining movements generated by elementary schools football players were conducted with thresholds of 6 G and 8 G thresholds. The top movements for which the composite acceleration is above 6 G are slow-down, shuffling (a large braking movement during sprinting/running) and stop movements. Similar movements are also included at 8 G and above, suggesting that the 6 G and 8 G thresholds are sufficient to extract the movements required for football. In the present study, no differences were found in the frequency of synthetic accelerations at 6 G and 8 G between grades. This suggests that high-impact movements do not differ between grades. However, interesting results were obtained in terms of the frequency of occurrence of composite acceleration at 4 G and above, with higher values in grades 5 and below compared to grade 6, and significantly lower values in grade 6. The apparent increase in impacts above 4 G, despite the fact that the distance traveled did not decrease, suggests that the frequency of impacts occurring at around 4 times the body in running and other movements, rather than in high-impact movements such as changes of direction, is higher in grades 5 and below the synthetic acceleration generated by the triaxial accelerometer correlates with ground reaction force [12] and is used as an indicator of impact. The phenomenon of the frequency of synthetic acceleration decreasing from the sixth grade suggests that impacts occur at a high frequency until around the fifth grade. In other words, in the lower grades, it is difficult to control the body using the knee as a shock absorber, and thus accelerations of 4 G or more occur more frequently during normal movement movements. As a result, repeated direct impacts on the heel can be expected to cause cumulative load on the heel.

From the perspective of preventing sports injuries during the growth period, it has been reported that calcaneal osteoporosis (Sever's disease) is common in the fifth grade of elementary school, around the age of 11 years [5]. However, as the school year progresses, Osgood's disease becomes more common from around the age of 12, which is the sixth grade [4]. The difference in the mechanism of occurrence of these disorders is that in calcaneal apophysitis, high-impact loads such as running or jogging are applied directly to the heel [17]. Osgood's disease, however, is thought to be caused by eccentric contraction of the quadriceps muscle, which stresses the tibial rough surface, showing a difference in the mechanism of occurrence. The results of the present study suggest that the transition of shock-absorbing movements occurs around the 5th and 6th grades, so that around 11 - 12 years of age is the age at which changes in characteristic sports disorders occur. The differences in the frequency of synthetic acceleration in the present study may be proposed as differences in the mechanism of the development of sports injuries in children.

A potential limitation of this study is that it is a cross-sectional study which reflect population and habits. Since elementary school children grow rapidly, it would be desirable to observe individuals in order to capture changes due to the growth process. In addition, only the frequency of trunk acceleration occurring during a football match was examined, and confirmation of what playing movements cause high acceleration has not yet been completed. It has been reported that knee joint injuries (anterior cruciate ligament injuries) occur during backhand strokes in badminton, and investigation in to movements associated with sports injuries is under investigation. Finally, examining these impact movements may help to elucidate the mechanisms associated with sports injuries.

5. Conclusion

In this study, a comparative study was conducted to determine whether the synthetic accelerations (4 G, 6 G and 8 G) that occurring during a game in elementary schools football players differed between different grades. The results showed that in 4 G and above, the frequency of synthetic acceleration per minute was significantly higher in grades 5 and below (36.98 ± 10.25 - 38.87 ± 10.14 counts/min) than in grade 6 (20.07 ± 7.71 counts/min), while in 6 G and above 8 G Synthetic acceleration generated by triaxial accelerometers is correlated with floor reaction force and is used as an indicator of impact. The phenomenon of a decrease in the frequency of synthetic acceleration from the sixth grade suggests that impacts occur at a high frequency until around the fifth grade of elementary school. As it has been reported that calcaneal osteodystrophy (Sever's disease) is more common in the fifth grade, around the age of 11 years, the difference in the frequency of synthetic acceleration occurrence in this study may be proposed as a difference in the mechanism of heel sports injury occurrence in children.

Disclosure statement

The authors declare no conflicts of interests.

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