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Original Article

Soccer heading evaluation during learning process using an accelerometer

MIRIAM KALICHOVÁ[1], MILOŠ LUKÁŠEK[2]
[1]Faculty of Sport Studies, Department of Kinesiology, Masaryk University, CZECH REPUBLIC
[2]Faculty of Sport Studies, Department of Athletics, Swimming and Outdoor Sports, Masaryk University
CZECH REPUBLIC

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Abstract:

Heading is one of the basic game activities in football but it is still discussed in term of risk of health problems, especially cumulative head trauma. This study aims to find out how to improve the supervision over heading performance during learning process in youth footballers using an accelerometer. The research sample consisted of 63 footballers from age groups U11 – U17. Each person executed headings of a ball dropped from 0.5 m, 1 m, and 1.5 m. A triaxial accelerometer fixed to the back of the head was used in the measurements. For individual groups of participants, an approximate linear increase in peak head acceleration was observed for an increase in ball drop height ($R^2 = \pm .99$). Furthermore, strong correlations in the maximum head acceleration parameter a_{max} were found between the attempts from all three heights. A linear decrease in peak head accelerations were observed with increasing age of the participants. The core importance lies in between relations of measured variables that show changes during acquisition of skills in heading in young footballers. Regular control accelerometer measurements can help determine the level of acquired skill and serve as an appropriate tool for preventing overloads or injuries of individuals.

Key Words: kinematics, football, impact, child

Introduction

In football, ball heading and its influence on brain functions cause increased concerns. This specific game feature is a regular part of training and matches. As previous studies suggest, the average number of headings during football matches has significantly increased in the last twenty years. Studies by Smodlaka (1984) and Sortland and Tysvaer (1989) state that on average, footballers head the ball 5-6 times during a match. Later studies raised this number up to 6-12 on average (Levy et al., 2012; Spiotta, Bartsch & Benzel., 2012). A sum of 12 headings per each practice must be added to the average rate, if we include trainings (Jordan, Green, Galantly, Mandelbaum & Jabour, 1996). A professional soccer player receives about 800 heading impacts each season (Levy et al., 2012). Lipton et al. (2013) have discovered a threshold value of approximately 885 to 1550 headings per year. It may be speculated from the data that headings of sufficient cumulative load may lead to neuropsychological deficits of the footballer and therefore needs to be examined thoroughly.

These impacts individually do not amount to such level to become a cause of a concussion. If any neuropsychological deficits are due to heading in football, they are likely, at least initially, to be sub-clinical in nature (Rutherford, Stephens & Potter, 2003). This statement is consistent with the suggestions by Babbs (2001) that proper heading techniques are unlikely to cause brain injury based on simulated safe exposure levels inferred to by the HIC (Head Injury Criterion). Furthermore, some studies did not specifically associate heading training with neuropsychological deficits (Rieder & Jansen, 2011; Stephens, Rutherford, Potter, & Fernie, 2005). However, neuropsychological literature states that repeated minor head injuries result in structural damage, traceable in neuropsychological tests (Dezman, Ledet & Kerr, 2013; Goodman, 1994; Gronwall & Wrightson, 1975; Mehnert, Agesen, & Malanga, 2005; Taha, Hassan, Aris & Anuar, 2013).

Rutherford, Stephens and Potter (2003) mention two causes of cumulative injuries in football. In the first case, there may be a residual effect of concussive injury that increases as the number of such injuries rises, especially when a latter acute injury occurs before the previous one has healed up. The second cause of cumulative head trauma in football are small, subliminal yet frequent impacts that do not cause concussive injuries themselves. They lead to micro-traumatic injuries causing chronic brain damage. According to Lynch and Bauer (1996), the head acceleration is a more determining factor causing injuries than the impact force. Nauheim et al. (2003) specify that high angular acceleration is more threatening than linear acceleration.

Head acceleration during football heading is influenced by several factors. Comparing novices and adult footballers Kerr and Riches (2004) concluded that higher head acceleration in beginners may be caused by

Corresponding Author: MIRIAM KALICHOVÁ, E-mail: kalichova@fsps.muni.cz

lower neck muscle strength. A similar conclusion was submitted by Dezman et al. (2013, p. 320), i.e. "the neck strength difference positively correlated with angular head acceleration (r = .497; p = .05), with a trend toward significance for linear head acceleration (r = .485; p = .057)". Tysvaer and Storli (1981) mention that when footballer is expecting the impact so that he can head the ball correctly, the effects of the impact force are minimized by neck muscle activity. According to Mehnert et al. (2005, p. 392) it is still not definite "how much of the force of impact received by the head is conveyed to the soft tissue structures of the neck, or how much is dissipated by the neck muscles and transmitted to the bony structures and joints of the cervical spine". Another factor which correlates with increasing angular and linear acceleration is the mass ratio of the ball to a player's head (Queen, Weinhold, Kirkendall & Yu, 2003). Babbs (2001) states that not even the use of a smaller, size 4, ball adequately compensates for the smaller effective mass of younger players. Additional potential risk factors influencing acceleration include heading technique, horizontal speed, inflation pressure of the ball, and speed of the player (Babbs, 2001; Erkmen, 2009).

Modelling and measuring head acceleration has been carried out in adult footballers by most authors (Babbs, 2001; Naunheim et al., 2003; Taha et al., 2013, and others). Novices and youngsters have been lately covered by only a minority of authors such as Babbs (2001), Hanlon and Bir (2012), Queen et al. (2003), Riches (2006). Dezman, Ledet, and Kerr (2013, p. 320) refer to Queen et al. (2003), when they state: "In particular, children learning the game have a greater head-to–ball size ratio and lower neck strength, putting them at risk for head injury". Based on these facts "children aged 10 and under have been banned from heading the ball in the US" (Al-Samarrai, 2015, p. 1).

Using accelerometry, we aim to identify head kinematic parameters for ball impacts and their changes in young footballers of various age categories. Firstly, we hypothesized that the intensity of head reaction to the ball hitting significantly depends on speed of a ball falling on a head, which will be determined by measuring head acceleration during heading. Secondly, we hypothesized that the maximum head acceleration acquired during heading is associated with age of young football players. On the basis of these relationships, we want to determine whether accelerometer is suitable as a tool for identifying changes in the heading technique which are not evident from the ball motion after impact.

Material & methods

Participants

The research sample consisted of footballers of four age categories U11 – U17. Included in the study were 16 players with average age of 10.3 years (range of 9.8 – 10.8) (U11), 15 footballers with average age of 12.4 years (range of 11.3 – 12.7) (U13), 18 players with average age of 14.4 years (range of 13.3 – 14.7) (U15), and 14 players with average age of 16.3 years (range of 15.3 – 16.8) (U17). Thus, a total of 63 footballers participated in this study whose characteristics are specified in Table 1 (average age, practice duration, duration of training units per week, and duration of played matches per week). As noted in the table, footballers' age and practice duration are related. This is due to the fact that the footballers included in the research were selected from groups of children who train from 7 years of age and continue to do so during subsequent years. A few additional footballers were selected from outside groups.

This project has been approved by the Ethics Committee of XXX (No. 4/2014). The informed consent was obtained from parents/legal guardians of minor participants.

Table 1 *Characteristics of research sample*

group	*N*	age	min age	max age	practice age	training h/week	matches h/week
U11	16	10.3	9.8	10.8	3	5.5	1
U13	15	12.4	11.3	12.7	5	7	1
U15	18	14.4	13.3	14.7	7	9	1.2
U17	14	16.3	15.3	16.8	9	8	1.3

Instruments

The head kinematic measurement device contains a printed circuit board with a battery holder for three AAA batteries. A sensitive unit MPU-6000 is placed on the board (http://www.invensense.com/products/motion-tracking/6-axis/) containing a tri-axial accelerometer and tri-axial gyroscope. The sensitivity of the unit is programmed to a maximum range, i.e. ±16g in each axis and uses a 16-bit A/D converters. A sample frequency of 1 000 Hz was used. A microprocessor, microSD card holder, a button and indicator LED light are on the board. Every time the device is switched on, the content of micro SD card is deleted and replaced by a new measurement. Due to the sensor sampling frequency, the data is saved to the micro SD card in the 'raw state', i.e. with no file system. Therefore in order to download the data into a computer it is necessary to use a programme capable of reading the saved data from the card. The card capacity (2 GB) enables up to 70 hours of measurements, depending also on the type of batteries used. The dimensions are 60x38x16 mm, the weight is

38*g*. The resting state noise was measured at Department of Physics Faculty of Science XXX and are of values a_x = 0.49 m/s2, a_y = 0.36 m/s2, a_z = 0.52 m/s2.

Software: A programme 'SD Card Downloader', designed at VUT Brno for data downloading, is set up to zero the sensor noise. A programme 'Next View 4.6 Analyse' (http://www.nextview.de/en/data-acquisition-software.html) was used for data processing while MS Excel® was used for data presentation.

Procedure

In the published studies the authors (Camarillo, Shull, Mattson, Shultz, & Garza (2013), Higgins, Halstead, Snyder-Mackler, & Barlow (2007), or Siegmund, Guskiewicz, Marshall, DeMarco, & Bonin (2014)) recommend placing the measuring device into the mouth when measuring head acceleration mainly due to a fact that an accelerometer attached to mouth represents the motion of the head centre more precisely than when attached to the helmet. Another reason for this recommendation is a fact that in case of impact the helmet can move which leads to data distortion. The helmet used in the study was an American football helmet which might move on head in case of impact. Also, its considerable volume probably causes that accelerometer attached to its surface shows different results than the head centre. Due to the fact that we tested sportsmen from the age of 10, the placement of accelerometer in their mouth was not comfortable and had invasive character. From this reason we chose to attach the device on the vertex of head. Considering the geometry of head, this point is located at almost same distance from the centre of head as if the accelerometer is located in mouth. In order to prevent any movement of the measuring device, the subjects were wearing silicone swimming cap which created anti-skid surface. The accelerometer unit was fixed to a footballer's head using a specially created headband; a flexible band with silicon surface with a clamp so that it can be tightened as needed. The headband was also secured using two rubber bands crossing at the vertex to reduce movement of the accelerometer unit. The accelerometer unit was inserted into a tight pocket sewed into the circumference band located at occipital bone so that a positive direction of one of the axes led from the forehead to the back of the head i.e. in the direction of the heading motion.

After the device was activated, it was fixed and the footballer prepared himself for the performance. Once the device was switched on, old data was purged and new data was ready to be saved. The initial position of the device on the head was recorded and the footballer subsequently initiated the ball impact. After the performance was finished, the device was switched off. For the testing a FIFA quality tested ball was used i.e. a ball of size 4 for U11 and U13, size 5 for U15 and U17.

The testing took place indoors during a regular afternoon training session. Within this pilot study we set the measurement conditions so that they meet the abilities of the youngest tested footballers, average aged 10. The height from which the ball was dropped was measured before each measurement using a fixed measuring instrument with a movable calliper which determined the vertical distance 0.5 m, 1.0 m, and 1.5 m from a footballer's head. At this height the examiner holds a ball, 20 cm in front the footballer's forehead so that the participant sees the ball with only minimum neck retroflection and with no retroflection of chest. After the examiner counted down, the ball was dropped with no initial speed and without rotation. The footballer's were to head the ball as far as possible, maintaining foot contact with the ground and with maximum effort and accuracy. An acceptable heading was when the ball flew into the delineated place. This was given by a minimum distance of 3m into which the ball was supposed to land, the angle sector was 10°. The schematic of the test setup is depicted in Figure 1. The footballer performed an initial test heading to familiarize themselves with the test conditions. Then, measured attempts were performed. Only those which fulfilled the targeted heading conditions were included in the research. Based on this methodology, one successful attempt from each height was sufficient. The total number of valid attempts was 189.

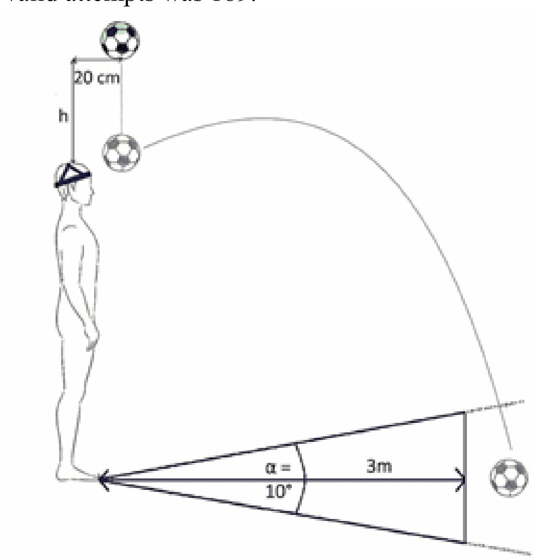

Fig. 1 Schema of the situation

Data analysis

Raw accelerometer data were downloaded from the SD card to the computer using 'SD Card Downloader' programme. The data were saved in an ASCII format (.csv), 6 columns of data, 1 000 entries per second. The data were then processed by a Next View 4.6 Analyse programme where each column was opened as an output of a single channel. The required column (a-f, channel 1-6) was placed onto a graphic display, where the observed area of data axis was zoomed in via a selection. The data area on time axis was defined using cursors and was then processed. The results were exported in ASCII format for graph creation, presentation, and interpretation of results in Excel programme. Non-filtered data were used for calculations and graphs.

From the data measured we were mainly interested in values of peak linear resultant acceleration of a head during the impact of the ball to the head and time characteristics to which the function of this variable relates. The measured accelerations are the dependent variable in our research, the independent variable is age, or the duration of practice.

Statistical analysis

Given the data (maximum head acceleration in heading with a ball dropped from three different heights - 0.5 m, 1 m, and 1.5 m) were normally distributed, which was verified via Kolmogorov – Smirnov test ($p = 0.05$), we used Pearson Correlation Coefficient to establish the relations between results of measurement in 0.5 m, 1 m, and 1.5 m ball drop. To predict the acceleration we established regression lines in the graphs. Furthermore, Analysis of Variance and consequently post-hoc test were used, i.e. Scheffé's method for evaluation of apparent differences between measured accelerations in groups U11, U13, U15, and U17.

Results

Typical resultant linear acceleration response curves of the head is shown in Figure 2 for impacts with balls dropped from 0.5 m, 1 m, and 1.5 m having computed vertical velocities of 3.13 m/s, 4.43 m/s, and 5.43 m/s, respectively.

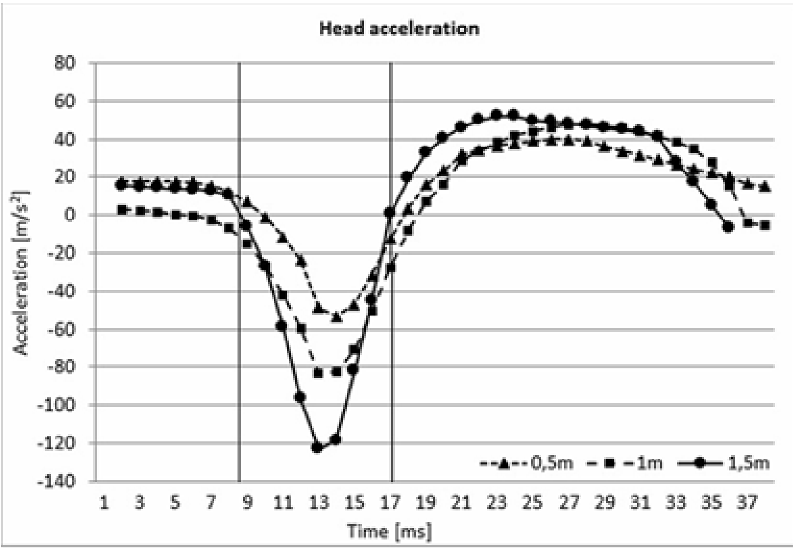

Fig. 2 Typical acceleration curve of the head during contact with a ball dropped from 0.5 m (dotted), 1 m (dashed), and 1.5 m (full line)

Table 2 *Average values of maximum linear acceleration (average), standard deviation (SD), minimum (min), maximum (max), range (R), and coefficient of variation (CV) when contacting the ball falling from 0.5 m, 1 m, and 0.5 m*

	a max /0.5 m (m/s^2)				a max /1 m (m/s^2)				a max /1.5 m (m/s^2)			
values	U11	U13	U15	U17	U11	U13	U15	U17	U11	U13	U15	U17
average	-59.4	-50.2	-44.1	-33.8	-76.4	-73.9	-69.1	-53.3	-100.1	-96.9	-87.5	-78.3
SD	15.8	16.3	20.3	13.3	15.0	21.9	30.3	21.6	25.0	27.7	36.1	24.8
min	-39.3	-20.0	-22.2	-14.7	-52.1	-45.0	-36.1	-19.6	-61.2	-52.2	-36.3	-36.2
max	-94.4	-76.2	-97.4	-70.5	-113.8	-107.7	-122.6	-90.8	-154.6	-150.8	-148.2	-117.7
R	55.1	56.2	75.2	55.8	61.6	62.7	86.5	71.2	93.3	98.6	111.9	81.5
CV	26.6	32.4	46.0	39.3	19.6	29.7	43.9	40.5	25.0	28.6	41.2	31.6

From the complete timeline of the impact event we focused mainly on the time sequence marked by two verticals in the graph. This is the instance when the forward motion of head is slowed down by the impact of a ball. The figures of maximum linear acceleration measured are shown in the Table 2.

In all groups of footballers (U11, U13, U15, and U17) the values of negative head accelerations increase with increasing ball drop height, and correspondingly, with increasing speed of the ball hitting the head. In a group of footballers U11 we found out that the average peak head acceleration was -59.4 ± 15.8 m/s^2 for 0.5 m, -76.4 ± 15 m/s^2 for 1 m, and -100.1 ± 25 m/s^2 for 1.5 m, or respectively -6 ± 1.6*g*, -7.8 ± 1.5*g*, and -10.2 ± 2.6*g* (*g* = 9.81 m/s^2). We can also see the increase in acceleration in the group U13 (-5.1 ± 1.7*g*, -7.5 ± 2.2*g*, -9.9 ± 2.8*g*), in the group U15 (-4.5 ± 2.1*g*, -7 ± 3.1*g*, -8.9 ± 3.7*g*), and in the group U17 (-3.5 ± 1.4*g*, -5.4 ± 2.2*g*, -8 ± 2.5*g*). It is apparent that the most advanced group of footballers U17 demonstrated the lowest values of measured negative head accelerations while we established the highest values in the youngest footballers U11. We can note that for the ball dropped from 0.5 m an average value of acceleration of -3.5*g* was measured in U17, which is approximately two times lower than in group U11, where it was -6*g*.

Intra-individual Data Assessment - Within the intra-individual analysis, we investigated the relationship between the maximum negative head acceleration and impact speed related to the ball drop heights of 0.5 m, 1 m, and 1.5 m. The Pearson correlation coefficient was used for the statistical analysis of all 63 footballers. A statistically significant relation was established in all cases between maximum head acceleration and ball impact speed. For the relationship between $a_{max0.5m}$ and $a_{max1.0m}$ (p □ .05) the correlation coefficient r = .76 was established, for $a_{max1.0m}$ and $a_{max1.5m}$ r = .78, for $a_{max0.5m}$ and $a_{max1.5m}$ r = .70.

Inter-individual Data Assessment - In the inter-individual data assessment we evaluated whether the differences between four groups of footballers (U11, U13, U15 a U17) are statistically significant. It is apparent from basic statistical characteristics (Figure 3) that the older footballers achieve lesser average negative peak head accelerations than younger ones.

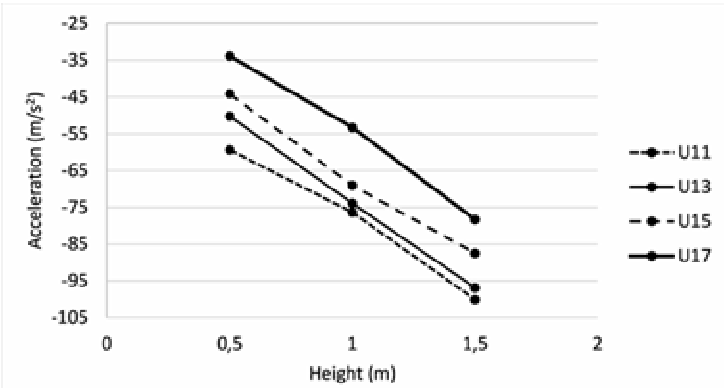

Fig. 3 Peak head accelerations at various ball drop heights of 0.5 m, 1 m, and 1.5 m ball drop heights for groups U11, U13, U15, and U17

As observed from Figure 3, the peak linear head accelerations decrease in linearly with increasing height from which the ball is dropped. It is worth mentioning that despite linear growth of the ball drop height the head impact speed followed the non-linear relationship $v = \sqrt{2hg}$. However, for the small increments in ball drop height, such as in our case, the velocity change can be approximated in a linear manner.

The regressions in Figure 4 show in all cases, much like in the heading of balls dropped from 0.5 m, 1 m, and 1.5 m heights, an almost linear progression of maximum acceleration for all groups U11, U13, U15 a U17. A regression coefficient of R2 = .99 supports the use of a linear approximation for the head acceleration responses in the 0.5 m ball drop tests. For the 1 m and 1.5 m ball drop tests, the regression coefficients are R2 = .85 and R2 = .96, respectively indicating a lesser predictive power of the linear regression. It was also observed that with increased age of the footballers there was a decrease in the negative head accelerations for similar ball drop heights

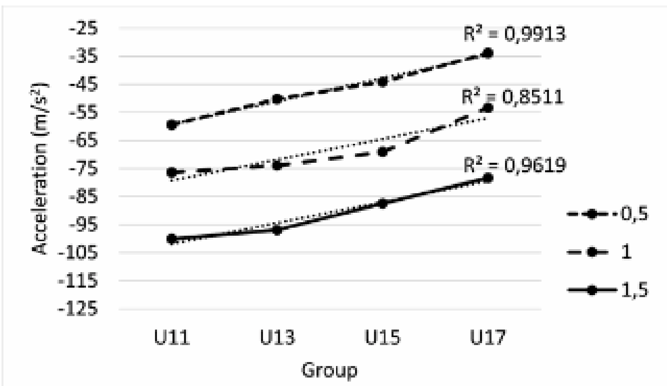

Fig. 4 Linear regression of peak head accelerations for various ball drop heights

We used the Analysis of variance to evaluate differences between groups U11, U13, U15, and U17. Consequently a Scheffé's test was applied. A statistically significant difference (p = .05) was confirmed merely in heading with ball-drop height 0.5 m and only in groups U11 and U17 (.0025). The interpretation is that only footballers in U17 were heading with significantly lesser negative head acceleration than U11 footballers. This happened only in the first measured situation (h = 0.5 m), whereas footballers from U13 and U15 were not statistically significantly different from the other two groups.

Dicussion

With respect to conditions we set, our results are comparable to data published by Taha et al. (2013). By measuring head movement in heading a ball falling from different heights and using an accelerometer we recorded acceleration values 1.5 - 15.8*g*. The vertical speed of the ball varied from 3.13 – 5.43 m/s. Taha et al. (2013) modelled and also measured head acceleration in ball impact dropped from 0.5 m, 1 m, and 1.5 m and recorded peak resultant linear accelerations of approximately 4*g*, 5*g*, and 6*g*. In the current study, average peak resultant accelerations were 4.8*g*, 7*g*, and 9.3*g*. As the research by Taha et al. focused on adults, we compare their results to those of our oldest tested group U17, i.e. 3.5*g*, 5.4*g*, and 8*g*. Here we can clearly see this values are close to results of Taha et al. (2013). Limitations with the Taha et al. study may exist, however, as the work was based on numerical simulations validated with a dummy head. No validation of the dummy head to human response was carried out.

All our tested groups U11 – U17 show the highest standard deviation in the third test (1.5 m) which by nature of the calculation increases with increasing magnitude of the values. In comparison, coefficients of variation, being normalized to the mean value, are almost equal in all cases (0.5 m; 1 m; 1.5 m). Comparing their values between the football groups we can state that in the mature groups, i.e. U15 and U17, the coefficients of variation are higher (CV 44% and 38% on average) than in the younger sportsmen in U11 and U13 (CV 24% and 30% on average). This implies that the response of the younger groups was more homogeneous than compared to the older groups, which was quite unexpected as we might have presumed that with advancing mastery of heading the measurements in individuals would be closer. Here it should be verified whether the differences in variability are due to the fact that sportsmen in groups U15 and U17 find themselves in a phase of dynamical physical development so their somatic and anthropometric parameters differ more within this age group compared to younger footballers (U11 a U13).

It is obvious that lower values of maximum head acceleration are considered to be a manifestation of better performed heading, while high values of backward head movements are manifestation of lower quality of the performance. With regards to the intra-individual results, using the Pearson correlation coefficient we found statistically significant relationships between the individual attempts of a given participant (p □ .05, r = .7 – .78). Therefore, consistency in quality of performed headings from the three different heights can be observed in the given participant. This means that in most cases the participant performs repeatedly under-average, average, or above-average performance, as it was in the three attempts (h = 0.5 m, 1 m, and 1.5 m) of the individual. The mentioned statistical significance proves a certain stability in participant's performance which is understood as an ability to repeatedly perform at a certain level (Dovalil, 2002).

With respect to a fact that the process of heading lasts a very short time, (± 0.01 s, as obvious from Figure 1), a coach can assess the quality of heading only based on the characteristics of ball flight, such as accuracy or distance of the flight. For this reason we see accelerometry as feedback for trainers. Results show that already a few measurements can reveal which individuals have the minimum negative head acceleration at lower ball speed and are therefore suited for more demanding heading training. On the other hand it also detects which individuals are better to stick with remaining level of training so as not to over-strain the individual.

While evaluating differences between the groups, it is worth mentioning that with groups U11 and U13 a smaller and therefore lighter ball was used compared to groups U15 and U17. Our aim was not to create homogeneous conditions for all groups. Our intention was to establish differences between headings in various age groups of footballers working with balls of different weights. We wanted to create conditions close to real situations, i.e. we did not want the young players hitting heavier ball they were accustomed to and vice versa.

Statistically significant differences in the maximum head accelerations were found only between groups U11 and U17, using analysis of variance and Scheffe's test (0.0025). Despite this, a relationship with age can be observed in the regression curves showing an obvious tendency of decreasing maximum head acceleration with increasing age of the players. If we consider a fact that age differences between the groups are not significant and that the older ones (U15 and U17) were heading bigger and heavier balls, then it is recommended to investigate the effects of ball characteristics.

Further influence of the ball speed was sought through linear regression analysis. Babbs et al. (2001) stated that an average horizontal velocity of a ball being headed by players aged 9 – 13 is 7.1 m/s. Additionally, the higher accelerations for youth players are in the range 15 to 20*g* when combinations of high ball velocity, high inflation pressure, and bad technique occur. Hanlon & Bir (2012) showed for 13-year-old girls horizontal acceleration between 4.5 – 62.9*g*, which makes 20.4*g* on average which is comparable to Shewchenko, Withnall, Keown, Gittens, and Dvorak (2005) who reported peak resultant head accelerations in the 16-20*g* range for participants of 20-23 years of age under various heading conditions. Based on this data we can consider a peak head acceleration of 20*g* as a reasonable value achieved by footballers when heading during play. Regarding this average head acceleration in youth footballers we aimed to find out what velocity the ball needs in order to achieve these values in our tested individuals. The extrapolation results showed that the acceleration would correspond with a ball speed of 8.2 – 9.4 m/s in various age groups, with an average of 8.9 m/s. Previously published results state an average speed of a ball being headed approx. 12 m/s in order to reach 20*g* (Bayly et al., 2002; Naunheim, 2003). By comparing this speed with our data we observe that our extrapolated data are slightly lower in the youngest group of footballers (U11) by 3.8 m/s and for the older group (U17) by 2.6 m/s. This emphasizes the observation that young footballers reach similar head accelerations at lower ball speeds than for older footballers. It may also be noted that the increasing age of a footballer corresponds well with football practice duration in our research and likely contributes to reducing head accelerations with, presumably, reduced effects of related deficits, if any. This should be taken into account while planning training programs.

As stated previously, The US Soccer Federation banned heading in children under the age of ten (Al-Samarrai, 2015). Nevertheless, based on the already detected development of head acceleration changes during heading in footballers aged 10 – 16 years, we are of the opinion that in younger age groups, at least until U13, rules should be put into practice to limit heading of fast flying balls during matches. We are aware of difficulties that arise with attempts to push through such regulations, for this reason we suggest to apply this convention on standard situations where a significant ball speed is expected i.e. corner kicks etc.

After a corner kick, the ball is often played with a head of the forward players (Cook & Goff, 2006). Taking into account the heading conditions, we come to the conclusion that these have the potential to be significant in terms of impact exposure to the head. With the minimum of a 'small football pitch' 50 x 42 m an average length of a corner kick is 20 m on average. If the ball ascends under the angle of 27° (Cook & Goff, 2006; Winter, 1990) the player must kick off this ball at speed of 18 m/s in order to pass the ball over this distance. If we omit (for simplification) the rotation of the ball, air resistance etc., we may conclude that this is the velocity of the ball hitting the head of a player. Head accelerations of 33 – 36*g* are expected under these conditions for the various age groups when based on the linear regressions presented previously. We must point out that these are values corresponding with a situation when a player actively reacts to a flying ball. If the same happens to an unaware player the acceleration values would be even greater (Babbs, 2001). In order to restrict occurrence of this happening we strongly suggest limiting heading at trainings, especially with unprepared footballers.

In a kick-off from the gate of a small pitch and taking into account the greater elevation of the ball, we come to similar or slightly greater values than in the corner kick when a goalkeeper kicks the ball to the second half of the pitch, i.e. to a distance of 25 m or more. As we suggest that exceedingly hard impacts to the head should be prevented we conclude that the heading should be played by the torso instead or only played after hitting the ground when ball speed is decreased due to energy dissipation. According to Ištok (2009), a ball with a pressure of 1 bar dropped from a height of 1 m, with no added force or rotation, rebounds to half of the initial height. This means that half of the ball's potential energy is lost upon impact with the ground due to conversion of the energy to other forms (i.e. strain energy). The ball impact speed will therefore decrease by a factor of 1.4 since ball speed is proportional to the square root of the potential energy. This decrease in speed is, however, not inconsiderable as the above estimated corner kick-off speed of 18 m/s would decrease to 13 m/s.

Regarding the high percentage of success with corner kicks, practicing the heading technique in this circumstance is justifiable for older age groups (U15-U17) to allow mastery of the technique by the time the time they reach U19, because these players slowly start to play with adults. However an individual approach and the method of accelerometry should be employed first as mentioned above, so that the difficult headings are trained after the easier ones have been mastered.

Based on the literature reviewed and experimental results, our recommendations must also take into account the presence of additional performance limiting factors. We are not able to identify the contribution of the factors, whether it is the body weight (Queen et al., 2003), the power of neck muscles (Dezman et al., 2013; Kerr & Riches, 2004), concentration i.e. readiness for heading (Tysvaer & Storli, 1981), the level of acquisition of the heading skills (Babbs, 2001; Erkmen, 2009), or other variables. However, the strong correlation between heading tests within individuals and the large inter-individual differences across tests are of great importance for us because they confirm that younger people who have only began to acquire heading skills can perform these in a consistent manner, i.e. the heading motions are not random in nature. This finding can serve as grounds for further measurements in which we will be looking for factors limiting this performance in adults as well as in youths. It is arguable whether with progressing age and expertise that the trends will change as well (Hellebrandt, 2012). We can merely remark that in the scope of individual groups U11 – U17 that we can observe highly variable anthropometry and postures of individuals, which can be crucial for head movement and heading technique.

Conclusions

The current accelerometry system has shown potential for the measurement of heading technique in the field, albeit at lower ball impact speeds resulting in head accelerations less than 16*g*.

In regards to accuracy of the system, the observed similarity of results with other studies requires further investigation since the measured responses are influenced by the different measurement methods used and the lack of isolating the independent variables (i.e. impact direction, heading technique and head motion, neck muscle involvement, head and body mass, ball size, mass, and pressure). A more precise determination of the accelerometry system accuracy could involve paired comparisons with a reference system known to provide accurate measurements such as systems mounted to the dentition or use of a dummy head with internal sensors. Work by Camarillo, Shull, Mattson, Shultz, and Garza (2013), Higgins, Halstead, Snyder-Mackler, and Barlow (2007), or Siegmund, Guskiewicz, Marshall, DeMarco, and Bonin (2014) have elaborated on the limitations of different measurement methods.

Another aim of the study was to investigate changes in head response across footballers of different ages. A comparison of results within individual attempts suggested that young footballers of 10–16 years of age, have relatively consistent heading technique. In regards to individuals across age categories U11 – U17, we noticed large differences in head responses which suggested that these groups are not homogeneous. Despite this, the performance was graduated across the age groups.

The outcome of this research can provide a basis for further measurement of head response to ball impact during heading using accelerometry. Continuing research is required to identify which factors contribute to the ability of a player to absorb the impact to the head in individual age groups. With this, the process of training and acquisition of the heading skill could be optimized and the potential of related health risks, if any, minimized.

Although the issue of health aspects of football heading has been solved for several years, it is still unclear what its effect on the human body is. This study focuses on measuring the head impact intensity in young footballers in skill development phases. Using the accelerometer, we found that even small changes in ball velocity are statistically significantly reflected in the movement of the head. Further, we outlined how these parameters are related to the age of athletes. These findings increase our understanding of this issue with the results supporting the American Youth Soccer Organization's recommendation that children under the age of ten should not head the ball. Results also supports recommendation that young footballers should be continuously monitored during learning process of the skill. We are convinced that accelerometry is an appropriate tool for determining the head reaction to the ball impact. According to the results while hitting slower balls, the intensity and difficulty of further training of this skill should be chosen. Football coaches and parents could appreciate the health benefits for children and young athletes using relatively easy accelerometer measurements.

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