Risk factors for injury in talented soccer and tennis players

van der Sluis, Alien

Publication date:
2017

2

CHAPTER 2

SPORT INJURIES ALIGNED TO PEAK HEIGHT VELOCITY IN TALENTED PUBERTAL SOCCER PLAYERS

Alien van der Sluis, Marije T. Elferink-Gemser Manuel Coelho-e-Silva, Jannes Nijboer, Michel S. Brink, Chris Visscher

International Journal of Sports Medicine, 2014; 35:351-355

ABSTRACT

In young athletes, demands of sport are superimposed on normal growth and maturation. It has been suggested that this causes a temporarily increased vulnerability for injuries. We followed 26 talented soccer players (mean age 11,9 ± 0,84 years) longitudinally for three years around their adolescent growth spurt, called peak height velocity, to identify differences in number of traumatic and overuse injuries and days missed due to injuries. Peak height velocity was calculated according to the Maturity Offset Protocol. Numbers of injuries were calculated for each player per year. A repeated measurement analysis showed that athletes had significantly more traumatic injuries in the year of peak height velocity (1.41) than in the year before peak height velocity (0.81). A moderate effect size of 0.42 was found for respectively the difference in number of overuse injuries per player per year before (0.81) and after peak height velocity (1.41). Finally, a moderate effect size of 0.55 was found for difference between days missed due to injuries before (7.27 days per player per year) and during peak height velocity (15.69 days per player per year). Adolescent growth spurt seems to result in increased vulnerability for traumatic injuries. Afterwards athletes seem susceptible for overuse injuries.

Keywords: growth spurt, development, trauma, maturity, longitudinal study, sport, adolescent

INTRODUCTION

To attain an expert level of performance in soccer, many hours of deliberate practice are needed [12, 16, 20, 35]. In young athletes, substantial increments in training occur during pubertal years that correspond to the period of maximal annual gains in stature and body mass [11, 25]. This means that the demands of the sport are superimposed on those of normal growth and maturation. It has been suggested that high training load overlapping with maximal annual changes in growth increases the risk of sport injuries [9].

Several mechanisms are being mentioned in the literature to explain an increase in traumatic and overuse injuries during years of maximal growth. Changes in joint stiffness and a temporarily variation in bone density during the maximal rate of growth during the adolescent growth spurt, called PHV, have been linked to temporal 'skeletal fragility' and acute fracture incidence [4, 13, 15, 22]. Also, "adolescent awkwardness", (a period in which trunk length and leg length have already increased, but muscles still have to reach their full size and strength) is mentioned as a potential cause, as well as an imbalance between strength and flexibility following the adolescent growth spurt [8, 26, 34]. This may lead to abnormal movement mechanics and a decline in performance on motor tasks during the interval of PHV [3]. Possibly, this temporarily decline in essential motor performance during years of maximal growth contributes to an increase in traumatic injuries.

Concerning overuse injuries, changes in the length, mass and body composition are mentioned as potential causes [1, 9, 19]. Studies on youth soccer players found a growth-related increase in overuse injuries and a higher incidence of severe injuries with age into adolescence [2, 24]. Overuse syndromes like Osgood Schlatter Disease and Sinding Larsen Johansson Disease are also typically linked to growth [9, 21]. These changes put an increased stress on the muscle-tendon junctions, bone-tendon junctions (apophyses), ligaments and growth cartilage. Those tissues are not immediately able to deal with the increased stress, resulting in a temporary imbalance in load placed on these tissues and the capacity to deal with this load. Especially in elite youth athletes, where this imbalance is combined with intensive training this may increase susceptibility for overuse injuries. For example, chronic wrist pain occurred more in 10-14 year old elite gymnasts than in younger and older groups [9]. During puberty, the cartilage of the tibial tuberositas is weakened and repetitive forces (for example due to intense training) result in avulsion of segments of the cartilage and bone [21, 30, 31].

Longitudinal studies that follow injury incidence in relation to peak height velocity are lacking. Authors have pointed out the importance of examining how injury incidence and patterns evolve in elite youth players when they progress through the different age groups [24]. Young soccer players are often selected based upon chronological age groups and talented players tend to be exposed to more training hours, as well as training sessions and matches that are characterized by a higher intensity. Inter-individual variability in biological maturation probably corresponds to variation in readiness for sport and by inference in vulnerability to injuries [10].

Therefore, the purpose of this exploratory study was to follow talented soccer players longitudinally and identify differences in traumatic and overuse injuries before, during and after the maximal rate of growth during the adolescent growth spurt, called peak height velocity (PHV). Better understanding in how injury rates evolve prospectively in talented soccer players during different phases of PHV is relevant because it makes it possible to develop strategies to prevent youth athletes from becoming injured.

MATERIAL AND METHODS

Participants

Participants of this study were talented soccer players, which we defined as being selected for the talent development program of a Dutch professional soccer club. The level of competition within the Dutch professional soccer clubs and their development programs are among the highest in the world. All players competed on the highest level of their age category and belonged to the best 0.5% of the total number of players in their age group (National Soccer Association, KNVB). Participants were selected for the talent development program by the scouts, trainers and staff of the professional soccer club between the seasons 2002/2003 and 2006/2007. Anthropometric measures to predict PHV, were standard measures performed at the start of their selection for the talent development program. In this study, we only included those players who continued to participate in the talent development program for at least three years around their peak height velocity, with one year before, one year during and one year after experiencing their peak height velocity. Players who dropped out of the program during one of the three years around their peak height velocity were excluded, as well as players whose PHV started within 1,5 year from their selection for the talent development program. Of the approximately 120 players who have been selected for at least one year for the talent development program in the study period, 26 of them met all inclusion criteria and could be followed for three years around PHV. Players in this group had an average age of 11.9 (±0.84) years at the time of their first selection. They were heterogeneous in height and weight, with a mean height of 157,01cm (±9,14) and a mean weight of 45,89 kg (±9,52) at the time of their first selection.

The study fits the established ethical standards for sports medicine [18]. An institutional agreement was signed between the Faculty of Human Movement Sciences of the Rijksuniversiteit Groningen and the soccer club to assure data collection.

Peak height velocity

The algorithm derived from two longitudinal studies of Canadian youth and one of Belgian twins was used to predict the time the soccer players were before PHV in years, termed maturity offset (R = 0.94, R2 = 0.89, and SEE = 0.59) [29]. For males, equation 3 was used, which calculates maturity offset as follows: -9.236 + (0.0002708 * (Leg Length *Sitting Height)) + (-0.001663 * (Age * Leg Length)) + (0.007216 * (Age*Sitting Height)) + (0.02292 * (Weight/Height*100)). Afterwards, predicted age at PHV was estimated as chronological age (CA) plus maturity offset.

Finally, the year of peak height velocity was set by taking six months before and six months after the age at peak height velocity. Injuries in this year were compared to injuries in the year before the year of PHV (called pre-PHV) and injuries in the year after PHV (called post-PHV).

Injury data

The physician of the club diagnosed and recorded injuries during the period in which the soccer players were in the talent development program. The definitions and data collection procedures that were used follow the recommendations of the consensus statement for soccer injury studies, i.e. the FIFA registration system [17]. An injury was defined as: "Any physical complaint sustained by a player that results from a soccer match or a soccer training, irrespective of the need for medical attention or time loss from soccer activities." Injuries were reported if a player was unable to take full part in future soccer training or match play for at least 24 hours (time loss injuries) or if a player needed medical attention, but was still able to take part in training or competition (medical attention injuries). Traumatic injuries were defined as injuries that resulted from a specific, identifiable event. Overuse injuries were defined as injuries that resulted from repeated micro trauma without a single identifiable event. Injuries were classified according to location, type, mechanism and severity of the injury. The severity of the injury was defined as the number of days that the player was not able to take full part in competition or training: slight (no absence from training or match, also recorded as 'medical attention injury'), minimal (1-3 days time loss), mild (4-7 days time loss), moderate (8-28 days time loss), severe (more than 28 days time loss) and career ending injuries.

Calculation of exposure and injury incidence

Information on training and match hours in the three measurement periods was gathered through a questionnaire that players filled in for research purposes. In case of missing data, training and match hours were replaced by the average amount of training hours or match hours for the corresponding age category in that year. Training and match injury incidence was calculated as the number of injuries/1000-h exposure in training and matches.

Statistical analysis

Descriptive statistics (means and standard deviations) were calculated by measurement period (year before, year during or year after peak height velocity) for training and match injury incidence and for number of traumatic injuries, number of overuse injuries and missed days due to injuries. The assumption of sphericity (equality of the variance of differences between measurement moments) was met for our data ($p > 0.05$ for all dependent variables). Longitudinal changes were therefore investigated using repeated measures of analysis of variance (ANOVA) in SPSS 17.0 [14]. Post-hoc tests using the Bonferroni correction for multiple comparisons were used to compare scores on the three different measurement moments. Cohen's d was calculated as a measure to interpret the scores. An effect size of approximately 0.20 was considered small, 0.50 moderate and 0.80 large (8). All p-values were 2-tailed, significance was set at $p<.05$.

RESULTS

Injuries

During the period of data collection (three years for each player), 178 injuries were recorded among the 26 talented soccer players. About 61% of the reported injuries (108 occurrences) were time loss injuries and an additional 70 (39%) were classified as medical attention injuries. With one exception, all players had been injured at least once during the study period. Mean and standard deviation for the total group were 6.85 (±5.46) injuries during the three years. Most injuries were located in the lower extremities (82%). The most common injuries were muscle strains/ruptures/tears/cramps (57%) and joint/ ligament injuries (20.8%), followed by contusions/haematoma (12.9%), fracture/bone stress (5.1%) and concussion/nerve injuries (1.1%). 2.8% were classified as other injuries (see figure 1).

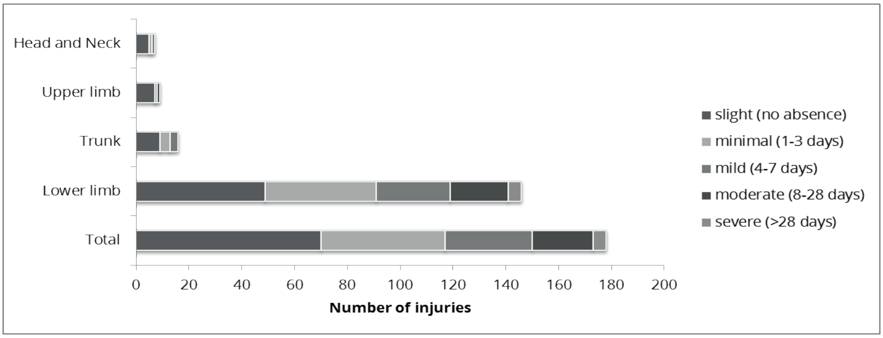

Figure 1. Injury locations (and severity) for 26 soccer players in the 3-year period around PHV.

Longitudinal comparisons

Table 1 and Figures 2a and 2b present injury incidence, number of traumatic injuries, number of overuse injuries and missed days due to injuries on the three measurement periods. A significant main effect for measurement period was noted F(14.00, 88.00)=1.602. p=0.046. Univariate tests showed a significant difference in number of traumatic injuries, F(2, 50)=3,768). Post-hoc tests using the Bonferroni correction for multiple comparisons revealed that number of traumatic injuries were significantly higher in the year of PHV than in the year before PHV (F(1,25)=3.320, p=.006, d=0.50.

Table 1. Mean scores (±standard deviations), effect sizes, F-values and p-values for injury incidence, traumatic injuries, overuse injuries, and days missed due to injuries in talented soccer players before, during and after peak height velocity.

	Means and standard deviations			Effect sizes (Cohen's *d*)			*F*-value	*p*-value
	Pre-PHV (n=26)	PHV (n=26)	Post	Pre-PHV *versus* PHV	PHV *versus* Post-PHV	Pre-PHV *versus* Post-PHV		
Traumatic injuries	0.81 ± 1.10	1.42 ± 1.33	1.39 ± 1.50	$0.50^{\#}$	0.03^{+}	$0.44^{\#}$	3,768	$0,030^{*}$
Overuse injuries	0.81 ± 1.41	1.15 ± 1.29	1.42 ± 1.50	0.26^{+}	0.19^{+}	$0.42^{\#}$	2,410	0,100
Missed days	7.27 ±10.05	15.69 ± 19.93	10.73 ± 17.77	$0.53^{\#}$	0.26^{+}	0.24^{+}	2,364	0,104
Training injury incidence	2.57 ±3.22	4.19 ± 4.13	3.84 ±3.48	$0.44^{\#}$	0.09^{+}	0.38^{+}	2,079	0,136
Training injury incidence (time loss)	1.59 ± 2.04	2.80 ±3.28	1.86 ± 2.41	$0.46^{\#}$	0.33^{+}	0.12^{+}	1,865	0,165
Match injury incidence	12.49 ±26.06	20.50 ± 28.00	23.08 ± 28.80	0.28^{+}	0.37^{+}	0.09^{+}	1,317	0,277
Match injury incidence (time loss)	9.43 ± 19.06	11.77 ± 19.86	15.91 ± 21.03	0.12^{+}	0.17^{+}	0.29^{+}	0,888	0,418

Note: d=0.20 (small$^{+)}$, d=around 0.50 (moderate$^{\#}$), d=around 0.80 (large$^{\wedge}$); *p <.05

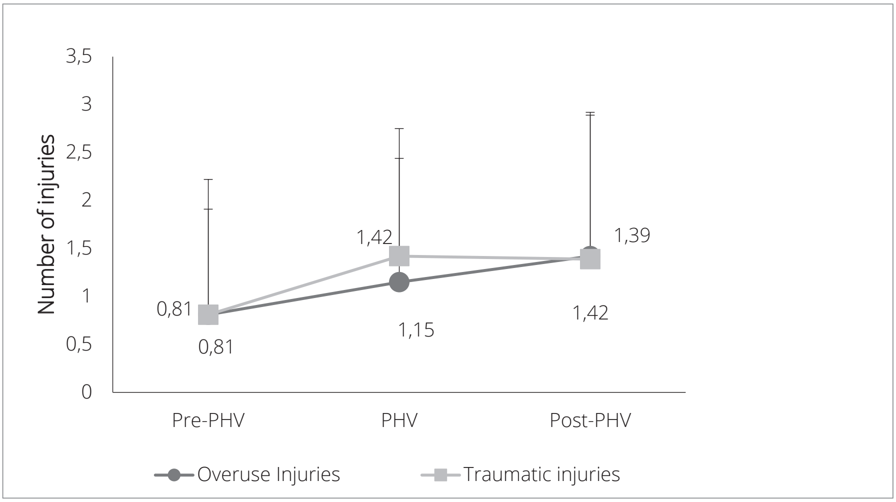

Figure 2a. Means and standard deviations for number of traumatic and overuse injuries in talented youth soccer players.

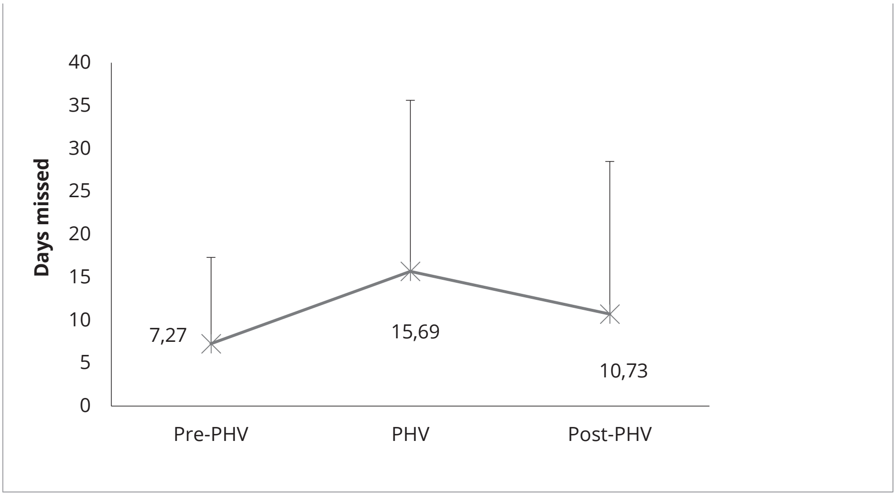

Figure 2b. Means and standard deviations for missed days due to injuries in talented youth soccer players.

DISCUSSION

The purpose of this exploratory study was to follow talented soccer players longitudinally and identify differences in traumatic and overuse injuries before, during and after the period overlapping with maximal rate of growth termed peak height velocity (PHV). First, the training and match injury incidences found on the three different measurement periods (year before PHV, year of PHV and year after PHV) give the possibility of making a comparison with incidences found in other studies. The repeated measurement analysis did not show a significant difference in match injury incidence over the three measurement moments. However, the tendency of the match injury incidence to increase over the three measurement periods is similar to that found in other studies addressing talented soccer players. For example, match injury incidences of 9.5 injuries per 1000 hours of match exposure in players under-14 years, 10.4 in under-15 players and 14.2 in under-16 players were found in a study in elite young soccer players [24]. Another study [32] documented an increment in injury incidence from 6 injuries per 1000 hours of exposure in players aged 14-16 years to 6.6 injuries per 1000 hours of exposure in players aged 16-18 years. Several authors stated intensity and competitiveness of soccer matches at older age as the probable cause for this [24, 33].

The training injury incidence found in this study increases during PHV and decreases thereafter for both total training injuries and time loss training injuries. Although there was no significant within subjects effect, moderate effect sizes were found for difference in training injuries between pre-PHV and PHV. In all three measurement periods training injury incidence of our study is lower compared to that of other studies [23, 24] which found rates of 3.7 to 4.1 per 1000 hours of practice. In contrast to the current study, the above mentioned studies only registered injuries that resulted in absence from training and competition for longer than 48 hours or even longer, whereas in line with studies investigating similar populations of talented soccer players [5], the current study registered injuries that resulted in 24 hours of absence or longer. This means that our training injury incidence would be even lower when we had used an even more strict definition of injury.

A possible explanation for this relative low training injury incidence is the select group of players in our study. After all, players were only included when they participated in the talent development program for at least three years, with one year before, one year during and one year after peak height velocity. This indicates a selection bias in favor of players being selected by the staff (who selected only the players they considered to be the best). Also, players who suffer from many injuries, have more days absence from training and competition. This will hinder their development as a player and decrease chances on being selected. Still, the results show an increase in injuries developed during training in the year of PHV, and a decrease afterwards. Match injuries increase more gradual over the three years, but when medical attention injuries are considered, it is possible to note a bigger increment from the year before PHV to the year of PHV (from 12.84 to 20.50) than afterwards (23.08). This could indicate an increased vulnerability of players during PHV. Also, the chance on developing an injury due to the action of an opponent (apart from one's own increased vulnerability) is bigger during matches than during training. So the influence of temporarily increased vulnerability resulting from PHV, is logically better seen in training injuries than in match injuries. The fact that training injury incidence increases during PHV and decreases afterwards, supports the idea of increased vulnerability during PHV.

The repeated measurement analysis showed a substantial increase in traumatic injuries from the year before PHV to the year of PHV. In the year after PHV, no differences were found.. More likely, the year of PHV is a year of vulnerability for talented soccer players when regarding traumatic injuries. Although no significant difference was found, the difference in training injury incidence and missed days due to injury between the year before and the year of PHV show moderate effect sizes.. Apparently, players develop more injuries during PHV and these injuries are more severe, causing more days of absence from training and/or competition.

It seems that an increase in traumatic injuries takes place mainly during the year of PHV, while the increase in overuse injuries persists in the year after PHV.

The factors that have been responsible for an increase in traumatic injuries (e.g. joint stiffness, decreased bone density, abnormal movement mechanics [15, 34]) have disappeared in the year after PHV, in contrast to factors contributing to overuse injuries. From a biomechanical perspective authors have explained causes for the increased occurrence of overuse injuries after growth spurt. First, changes in limb mass typically occur before changes in muscle tissue. Using only a conservative estimate of the change in limb mass of the lower leg during growth spurt, the muscles of the lower leg already need to develop about 30% more force after the growth spurt than before, to produce the same lower leg acceleration, for example required in a kicking movement like in soccer. If the muscles, tendons and apophyses associated with that muscle group adapt slowly, and activities are performed repetitively (like in talented soccer players), overuse injuries may occur [19]. Second, it is mentioned that the material properties of tendons change during maturation and that this results in an increase in strength. This increase, however, results as a response to exercise and also follows the increase in bone mass and muscle strength, leaving a period of increased susceptibility after PHV [18].

The current study has identified some interesting results regarding the development of traumatic and overuse injuries before, during and after PHV. However, some limitations need to be assumed. First, the sample size of 26 players is rather small. However, the fact that we were able to follow these players for three years around their PHV, adds to cross-sectional data on injuries so far. Additional longitudinal research on specific trends in injuries among talented soccer players is needed [24]. Second, it was not possible to conduct statistic tests in order to find differences in training and match injury incidence between before PHV, during PHV and after PHV. And last, age at PHV was based on the formula of Mirwald. Although this is a reliable, noninvasive and practical solution for the determination of age of PHV, some caution should be taken regarding the accuracy of the moment of PHV [29].

A recent study [27] evaluated the relationships among indicators of biological maturation and examined the concordance between classifications of maturity status in youth soccer players in two age groups, 11-12 and 13-14 years. Mean predicted age at PHV (13.9±0.4

years) was similar to the mean age at PHV for the boys upon whom the maturity offset protocol was developed (13.8±0.9 years). However, the standard deviation for predicted age at PHV in soccer players was about one-half of that for the three original longitudinal series. The discordant observation for predicted age at PHV based on the maturity offset protocol in soccer players 13-14 years may reflect error in the prediction equation which has a 95% confidence interval of 1.18 years [27]. The equation includes interaction terms for leg length and sitting height, age and leg length, and age and sitting height. The ratio of leg length to sitting height was, on average, slightly higher in the cross-sectional sample of soccer players compared to one of the longitudinal series upon which the maturity offset equation was developed, specifically one year before, at and one year after PHV. Sampling per se and/or population variation in the proportions of the extremities (leg length) and trunk (sitting height) may be additional factors.

Concerning practical implications of the current study, it is well documented that there are large individual variations in the timing of the adolescent growth spurt [6, 27]. Training schedules and talent development programs should take into account that individuals of the same chronological age can differ in their biological age and thus in the period in which they have their PHV. Several studies have pointed out that athletes more advanced in their biological maturity perform better than their late maturing peers and have a bigger chance on being selected [3, 26]. However, in most talent development programs to date, also in soccer, selection still takes place based on 1-year age groups and talented players are selected for the next age group when they are chronologically older and have sufficient quality. Often this means that in an advanced age group, players are exposed to more training hours than before, regardless of their biological age and regardless of being temporarily more vulnerable due to PHV. Soccer clubs dealing with talented players, should monitor growth of individual players and take precautions (e.g. in terms of biological age-group selections and training intensity) in periods of intensive growth. Further research should focus on the causes behind traumatic and overuse injuries in order to formulate appropriate actions (e.g. coordination training during PHV).

The present study suggests growth and maturation as potential risk factors for sport injury in talented soccer players. The period of PHV seems to result in increased vulnerability for traumatic injuries and in the period after PHV players seem susceptible for overuse injuries.

ACKNOWLEDGEMENTS

The authors would like to thank the medical staff and players of soccer club FC Groningen for their participation in this study.

REFERENCES

1. Adirim TA, Cheng TL. Overview of injuries in the young athlete. Sports Med 2003; 33: 75-81
2. Andreasen I, Faunø P, Lund B, Lemche P, Knudsen H. Soccer injuries among youth. Scand J Med Sci Sports 1992; 3: 62-66
3. Beunen G, Malina RM. Growth and physical performance relative to the timing of the adolescent spurt. Exerc and Sport Sci Rev 1988; 16: 503-540
4. Blimkie CJ, Lefevre J, Hodges NJ, Beunen GP, Dequeker J, Van Damme P. Fractures, physical activity, and growth velocity in adolescent Belgian boys. Med Sci Sports Exercise 1993; 25: 801-808
5. Brink MS, Visscher C, Arends S, Zwerver J, Post WJ, Lemmink KAPM. Monitoring stress and recovery; new insights for the prevention of injuries and illnesses in elite youth soccer players. Br J Sports Med 2010; 44: 809-815
6. Coelho-e-Silva MJ, Moreira Carvalho H, Gonçalves CE, Figueiredo AJ, Elferink-Gemser MT, Philippaerts RM, Malina RM. Growth, maturation, functional capacities and sport-specific skills in 12-13 year-old basketball players. J Sports Med Phys Fitness 2010 Jun; 50: 174-181
7. Cohen J. Statistical Power analysis for the Behavioral Sciences. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum Associates; 1988: 567
8. Davies PL, Rose JL. Motor skills of typically developing adolescents: awkwardness or improvement. Phys Occup Ther Pediatr 2000; 20: 19-42
9. Difiori JP. Evaluation of overuse injuries in children and adolescents. Curr Sports Med Rep 2010 Nov-Dec; 9: 372-378
10. Dudink A. Birth date and sporting success. Nature 1994; 368-592
11. Elferink-Gemser MT, Huijgen BC, Coelho-e-Silva M, Lemmink KA, Visscher C. The changing characteristics of talented soccer players- a decade of work in Groningen. J Sports Sci 2012; 30 (15): 1581-1591.
12. Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. Psychol Rev 1993; 100, 363-406
13. Faulkner RA, Davidson KS, Bailey DA, Mirwald RL, Baxter-Jones AD. Size-corrected BMD decreases during peak linear growth: implications for fracture incidence during adolescence. J Bone Miner Res 2006; 21: 1864-1870
14. Field A. Discovering Statistics Using SPSS. Sage publication, London, Thousand Oaks, New Delhi. 2nd Edition, 2005: 427-482
15. Ford KR, Myer GD, Hewett TE. Longitudinal effects of maturation on lower extremity joint stiffness in adolescent athletes. Am J Sports Med 2010; 38: 1829-1837
16. Ford PR, Ward P, Hodges NJ, Williams AM. The role of deliberate practice and play in career progression in sport: the early engagement hypothesis. High Ability Studies 2009; 20 Issue 1: 65-75
17. Fuller CW, Ekstrand J, Junge A, Andersen TE, Bahr R, Dvorak J, Haglund M, McCrory P, Meeuwissen WH. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Clin J Sports Med 2006; 16: 97-106
18. Harris DJ, Atkinson G. Update-ethical Standards in Sport and Exercise Science Research. Int J Sports Med 2011; 32: 819-821
19. Hawkins D, Metheny J. Overuse injuries in youth sports: biomechanical considerations.

Med Sci Sports Exerc 2001 Oct; 33: 1701-1707
20. Helsen WF, Starkes JL, Hodges NJ. Team sports and the theory of deliberate practice. J of Sport and Exerc Psychol 1998; 20: 12-34
21. Hirano A, Fukubashi T, Ochai N. Magnetic resonance imaging of Osgood-Schlatter disease: the course of the disease. Skeletal Radiol 2002 Jun; 31: 334-342
22. Iuliano-Burns S, Mirwald RL, Bailey DA. Timing and magnitude of peak height velocity and peak tissue velocity for early, average, and late maturing boys and girls. Am J Hum Biol 2001; 13: 1-8
23. Junge A, Rosch D, Peterson L, Graf-Baumann T, Dvorak J. Prevention of soccer injuries: a prospective intervention study in youth amateur players. Am J Sports Med 2002; 30: 652-659
24. Le Gall F, Carling C, Reilly T, Vandewalle H, Church J, Rochcongar P. Incidence of injuries in elite French youth soccer players: a ten-season study. Am J Sports Med 2006; 38: 928–938
25. Malina, RM. Early sport specialization: roots, effectiveness, risks. Curr Sports Med Rep. 2010; 9 (6): 364-371.
26. Malina RM, Bouchard C, Bar-Or O. Growth, Maturation and physical activity. Champaign, IL: Human Kinetics. 2004
27. Malina RM, Coelho-e-Silva MJ, Figueiredo AJ, Carling C, Beunen GP. Interrelationships among invasive and non-invasive indicators of biological maturation in adolescent male soccer players. J of Sports Sci 2012; 30 (15): 1705-17
28. Malina RM, Pena Reyes ME, Figueireido AJ, Coelho E Silva MJ, Horta L, Miller R, Chamorro M, Serrasota L, Morate F. Skeletal age in youth soccer players: implication for age verification. Clin J Sport Med 2010 Nov; 20: 469-474
29. Mirwald RL, Baxter-Jones AD, Bailey DA, Beunen GP. An assessment of maturity from anthropomtric measurements. Med Sci Sports Exerc 2002 Apr; 34: 689-694
30. Ogden JA, Southwick WO. Osgood-Schlatter disease and tibial tuberosity development. Clin Orthop Relat Res 1976 May; 116: 180-189
31. Ogden JA. Radiology of postnatal skeletal development. X. Patella and tibial tuberosity. Skeletal Radiol 1984; 11: 246-57
32. Peterson L, Junge A, Chomiak J, Graf-Baumann T, Dvorak J. Incidence of football injuries and complaints in different age groups and skill-level groups. Am J Sports Med 2000 Sept; 28: s51-s57
33. Price RJ, Hawkins RD, Hulse MA, Hodson A. The Football Association research programm: an audit of injuries in academy youth football. Br J of Sports Med 2004 Aug; 38: 466-471
34. Tanner JM. Foetus into Man. Physical growth from Conception to Maturity. London: Open Books; 1978: 75-83
35. Ward P, Hodges NJ, Starkes JL, Williams MA. The road to excellence: deliberate practice and the development of expertise. High Abil Stud 2007; 18: 119-15