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Influence of biological maturity on static and dynamic postural control among male youth soccer players

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ABSTRACT

Background: Peak height velocity has been reported to be associated with the phenomenon of adolescent awkwardness, a temporary disruption in motor skills, and an increase in injuries in some adolescents. To date, it is not entirely clear which motor abilities are deficient during the phase of rapid growth.

Research question: We hypothesized that static as well as dynamic postural control is influenced by biological maturation.

Methods: The study was conducted in a prospective, cross-sectional design. Maturity offset, a somatic indicator for biological maturation was captured for n = 99 male soccer players (13.7 ± 0.5 years). Static and dynamic balance were assessed by the Balance Error Scoring System (BESS) and the Y-Balance Test (YBT), respectively. Influences of biological maturation on balance performances have been analyzed by linear mixed models.

Results: Linear mixed model analyses revealed that biological maturation is significantly associated with the total BESS score ($p = 0.022$, $b = 2.195$) as well as the YBT anterior (right leg: $p = 0.023$, $b = -0.022$; left leg: $p = 0.015$, $b = -0.024$) and posteromedial reach directions (left leg: $p = 0.02$, $b = -0.029$). No significant associations were found for the other YBT distances.

Significance: Based on our results, maturation seems to have a considerable influence on postural control. It might be that deficits in balance performance contribute to the phenomenon of adolescent awkwardness and therefore lead to an increased injury risk during the adolescent growth spurt. To possibly prevent injuries in youth soccer, biological maturation should be taken into consideration in youth sport coaching.

1. Introduction

While chronological age follows a linear progression from the date of birth until death, biological age is characterized by interindividual differences regarding tempo and timing of its development [1]. Biological maturation is a crucial phase during growth and completed as soon as maturity is reached. While maturation describes a developmental process, maturity is a state at which all bodily tissues, organs and systems are considered fully developed. The mature state can be equated to adulthood [2]. Owing to the nonlinear character of the biological maturation process, there is the possibility of a fast and volatile change in maturation status in some adolescents, which can be associated with the phenomenon of adolescent motor awkwardness, a temporary delay or regression in sensorimotor functions following the adolescent growth spurt [1,3]. It has been shown, that adolescents situated in the phase of rapid growth or peak height velocity (PHV) respectively, underlie a significantly increased injury risk compared with the episodes before or after that stage [4]. The risk factors contributing to the rise in injury incidence are not unequivocally clear [3], and may include musculoskeletal characteristics like joint stiffness [5], changes in bone density [6], or variables of sensorimotor function such as static and dynamic balance control [3].

Static as well as dynamic balance control are fundamental for activities of daily living, recreational, fitness or sport specific tasks and impairments of balance have shown to be associated with an increased risk for lower extremity injuries [7–9]. Foot and ankle injuries predominantly occur during adolescence [10], which may be due to physiological changes during biological maturation.

While some studies investigated the influence of maturation on physical performance like the Functional Movement Screen (FMS) [11], or soccer specific tasks [12], only two studies examined the effects of biological maturity explicitly on balance control [13,14]. Duzgun et al. [13] investigated the effect of the Tanner stage, an indicator of sexual maturity, on proprioceptive accuracy using a one-leg-standing test

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among others for assessing their balance. The authors did not find any significant differences in static balance between early and late adolescent stages. Holden et al. [14] examined dynamic postural control in young adolescent athletes by using the Star Excursion Balance Test (SEBT). Results showed a decreased dynamic postural control on the SEBT in early adolescents compared with values published for older adolescents and college students. The conflicting results of both studies may be due to different methodological approaches regarding the assessment of biological age. The validity of the Tanner stage as an indicator of biological maturity can be questioned because of inaccuracy within a stage and privacy interventions [1,15]. Holden et al. [14] assumed that all participants were in an early pubertal stage at an age of 13 years. This assumption is presumably not applicable for every participant in the recruited study sample and therefore, conclusions based on these results should be interpreted carefully. Another explanation could be the different approaches regarding balance assessment. It has been shown that static and dynamic balance performance show a weak correlation and that results from static tests are not applicable to dynamic tasks [16]. Therefore, static and dynamic tasks should be performed to evaluate balance thoroughly [17].

Due to that lack of evidence-based knowledge, the aim of the present study is to investigate the influence of PHV as an indicator of biological maturity on the performance in static and dynamic balance as parameters for sensorimotor control. We hypothesize that, following physiological changes in the phase of rapid growth, static and dynamic balance control are influenced by maturation.

2. Methods

2.1. Participants

Using a prospective, cross-sectional study design, n = 101 male youth soccer players were recruited. Since PHV among boys is expected around 14 years of age [1,2], and decreases in sensorimotor function have been shown to occur between 13 and 14 years of chronological age [18], inclusion criteria were official registration in one of the recruited teams' under-14 or under-15 age group and regularly active participation in training and competition. The restriction on male youth soccer players is based on the statement that the phenomenon of adolescent awkwardness affects mainly boys [2]. Subjects with acute lower extremity injury have been excluded from data analysis.

The athletes' legal guardian provided written informed consents to the voluntary participation in this study. The study has been approved by the local ethics committee and followed the principles of the Helsinki Declaration.

2.2. Instruments

Chronological age, body height (seca 213, seca, Hamburg, Germany) and body weight (BF511, Omron, Kyoto, Japan) were recorded for all participants.

Biological maturity was determined using a maturity offset value based on anthropometric measures [19]. The following equation was applicated:

$$maturity\ offset = -7.999994 + (0.0036124 * (age\ [years] * body\ height\ [\mathrm{cm}]))$$

On this occasion, maturity offset means the temporal distance to PHV. A negative maturity offset indicates that PHV has not taken place yet, whereas a positive value implies that PHV has already occurred. The underlying formula's coefficient of determination (R^2) is 0.896. The standard error of estimation is 0.542. To receive an overview whether the participants have already passed through the PHV or not, a categorization into one of three maturity classes (pre-PHV, PHV, post-PHV) took place for every player. According to the method described by van der Sluis et al. [4], participants with a maturity offset of < -0.5 were categorized as pre-PHV, players with a maturity offset of > 0.5 were categorized as post-PHV and participants between these values were assigned in the category PHV. This procedure has become established practice in studies with adolescent participants [4,15].

The Balance Error Scoring System (BESS) and the Y-Balance Test (YBT) were used to assess static and dynamic postural control, respectively. Both assessments have widely been used and acceptable levels of validity and reliability were reported [9,20]. Both, the BESS and the YBT have shown to be appropriate instruments for the determination of static (BESS) and dynamic (YBT) balance ability in young, physically active individuals [21,22].

The BESS is an often used instrument to quantify static balance performance [20]. It consists of three different stance conditions (double-leg stance, single-leg stance and tandem stance) on two different surfaces (firm and foam). In contrast to the instructions that can be found in Bell et al. [20], the dominant limb (kicking leg) was defined as the stance leg during the one-leg stance and the rear leg during the tandem stance conditions. This procedure was based on the assumption that a soccer player's kicking leg might be more unstable than the non-kicking leg regarding balance ability. An Airex balance-pad (Airex AG, Sins, Switzerland) was used as foam surface. In total, six stance conditions have to be completed. Every condition lasts for 20 s. Eyes were closed and hands on hips during all trials. For each stance condition the number of occurred errors was counted and the absolute number of errors across all six standing conditions was calculated for data analysis. Errors were defined as opening eyes, lifting hands off the iliac crest, stepping, stumbling or falling out of the stance position, lifting forefoot or heel, hip abduction of 30° or more or being unable to return to the stance position after a fall in less than five seconds [20]. After detailed verbal instruction and demonstration by the tester, participants were asked to practice stance conditions on both surfaces in order to ensure that everyone is familiar with the task. To improve reliability, video capture was set up for every participant and each standing condition. Results were determined retrospective by one BESS-experienced tester who has several years of experience in evaluating BESS performance and therefore high expert knowledge in detecting errors.

The YBT is the shortened version of the SEBT and consists of three reach directions: anterior, posteromedial and posterolateral [9]. Based on the procedure described by Filipa et al. [23], participants were asked to place the tested leg's great toe in the middle of the three reach directions. With the other leg, subjects had to reach as far as possible in every direction while maintaining balance with the stance leg. Maximum reach distances for both legs in every direction were measured for the YBT performance. If one or more errors occurred during the execution, the trial in that direction, the mistake happened, had to be repeated. Errors are defined as being unable to maintain single-leg stance, shifting any part of the stance foot, lifting the heel of the stance foot from the floor, shifting weight onto the reach foot or hands losing contact with the iliac crest [9,23]. The reach distances were normalized to the leg length of the reaching limb using the distance from the anterior superior iliac spine to the center of the ipsilateral medial malleolus [24]. For example, while standing on the right leg and reaching with the left leg, reach distances were normalized to the leg length of the left leg and vice versa. To minimize training effects, all participants had the opportunity to practice before they performed three measured attempts. Subjects were not tested until they were familiar with the task. For data analysis of the YBT, maximum normalized reach distances in the anterior, posteromedial and posterolateral directions were used as dependent variables.

2.3. Data analysis

Differences in anthropometric characteristics between participants in the three maturity phases were determined using univariate analyses of variance.

Linear mixed model analyses were used to identify the relationships between biological maturity and static as well as dynamic balance. We analyzed how biological maturity predicts static and dynamic postural control. As the measures within each team may be more related than across teams, we chose a random intercept model (level 2: team affiliation). Maturity offset was included as fixed effect in both models predicting static (BESS) and dynamic (YBT) postural control. Statistical analyses were conducted using IBM SPSS Statistics (Version 23.0; Armonk, NY, USA). Level of significance was set at $\alpha = 0.05$ for all tests.

3. Results

Due to missing data on the baseline study protocol sheet, n = 99 participants (mean age 13.7 ± 0.5 years; mean height 165.1 ± 9.4 cm; mean mass 52.8 ± 9.5 kg) were taken into consideration for data analysis. At the time of data collection, the youngest player was 12.5 years and the oldest 14.6 years old. Body heights reached from 141.0 cm to 183.5 cm and body weights from 33.2 kg to 77.2 kg. Thus, ranges extended over 42.5 cm and 44.0 kg, respectively. The mean maturity offset value was 0.2 ± 0.6. The most immature player had a maturity offset of -1.3 years while the most mature player had a value of 1.6 years. Therefore, the maturity offset value's range is approximately three years. Only 17 players were classified pre-PHV while 47 were within and 35 post-PHV. Significant ($p < 0.001$) differences in anthropometric characteristics have been observed between participants in the three maturity phases (Table 1).

Linear mixed model analyses revealed that biological maturation significantly influenced static postural control performance ($p = 0.022$; $b = 2.195$). The total BESS score was lowest in participants with the lowest maturity offset. For the YBT, maturity offset was a significant predictor for performances in the anterior direction of the right ($p = 0.023$; $b = -0.022$) and left ($p = 0.015$; $b = -0.024$) leg as well as for the posteromedial direction of the left leg ($p = 0.020$; $b = -0.029$). The higher the maturity offset values the lower were the reach distances in these directions. No significant associations were found between the maturity offset and the posterolateral (right: $p = 0.256$, $b = -0.015$; left: $p = 0.168$, $b = -0.015$) and posteromedial (right: $p = 0.275$, $b = -0.011$) directions of the YBT (Table 2).

4. Discussion

The main finding of this study was that biological maturation is associated with changes in static and dynamic balance control. An increased static (lower BESS error score) and dynamic postural control (higher YBT reach distances) was observed among the participants with lower maturity offset values. Therefore, it seems that maturation influences postural control and so the original hypotheses can be accepted. Previous studies reported associations between maturity and an increased injury incidence [4,25]. The primary factors contributing to the increased injury risk during maturation, for example the adolescent awkwardness around the adolescent growth spurt are still mostly unknown [26]. Since a reduced postural control can be predictor for lower extremity injuries [7–9], we hypothesized that there might also be an association between postural control and biological maturity. The present results emphasize this assumption. It seems that the onset and the progress of the maturation process is related to impairments of sensorimotor control associated with standing balance performance. Adolescents situated in PHV experienced multiple physiological changes including fluctuations in postural control and other motor skills due to imbalances in physical development [1,4]. Following the rapid changes in body proportion an adjustment of motor patterns has been assumed by other authors [3]. The regulation of postural control depends on a finely tuned cooperation between the visual, vestibular and proprioceptive systems [27]. Changes in skeletal and muscle-tendon-structures during the adolescent growth spurt might disturb the proprioceptive ability and therefore reduce balance control [3]. Our data showed persisting impairments in postural control with increasing maturity offsets indicating that athletes in the post-PHV phase still have deficits in their balance skills.

Regarding an influence of maturity on balance control, conflicting results have been stated [13,14]. Our results are at least partly in agreement with the findings of Holden et al. [14] who demonstrated that deficits in postural control occur in early adolescents on the SEBT. Therefore, both investigations found limitations in postural control in male adolescents during maturation.

In our study population, YBT results slightly varied between limbs. One can only speculate regarding its reasons. It has been shown that YBT performance is not solely influenced by dynamic balance ability but also by limb strength and flexibility [9]. Thus, differences might be due to strength or flexibility imbalances. Another explanation could be the influence of unknown or chronic lower extremity injuries such as chronic ankle instability.

A few limitations in our study need to be addressed. First, although somatic determination of biological maturity based on equations with anthropometric variables is widely accepted in scientific literature [4,19,28], other assessment methods like skeletal age via radiographic captures might provide more accurate results [1]. Yet, a gold standard for assessing biological age has not been established [29]. In our study, biological maturity has been calculated based on the variables chronological age and body height. Of course, it remains doubtful how accurate biological maturity can be estimated by such simplified methods and how the participant's future adult height influences maturity offset determination. Nevertheless, authors found that this equation is accurate in average maturing boys and thus, the applied somatic maturity equation has its justification and is even an improvement of earlier developed formulas [15,19,28]. In addition, since the used equation was validated based on Caucasian adolescents [19] and all participants were of Caucasian ethnicity as well, race should not be a source of estimation error. Second, the BESS and the YBT are widely accepted, feasible and cheap postural control assessment tools [9,20], but they underlie a highly subjective component through the tester. Efforts have been undertaken to reduce reliability bias by video capturing every single stance condition and retrospective rating by the same BESS-experienced tester. Third, a consistent number of practice trials for the YBT could not be assured due to the simultaneous conduction of practice and measurement trials of different participants. A standardized procedure regarding YBT practice trials might have reduced the potential influence of training effects on dynamic postural control

Table 1
Participants' distribution in different maturity classes based on their maturity offset value. Mean scores (SD) for selected anthropometric characteristics and p-values regarding between-group differences.

	Pre-PHV (n = 17)	PHV (n = 47)	Post-PHV (n = 35)	p
Maturity offset [years]	−0.8 (0.2)	0.0 (0.3)	0.9 (0.3)	< 0.001
Chronological age [years]	13.2 (0.3)	13.6 (0.4)	14.2 (0.4)	< 0.001
Body height [cm]	151.9 (5.2)	163.3 (5.7)	173.8 (5.6)	< 0.001
Body weight [kg]	40.0 (3.1)	51.8 (6.6)	60.3 (7.8)	< 0.001

PHV = peak height velocity; SD = standard deviation; maturity offset < -0.5 = pre-PHV; maturity offset > 0.5 = post-PHV.

Table 2
Mean scores (SD) and 95% confidence intervals for the static and dynamic balance performances. Effects (b) and significances (p) of balance performances in association with the maturity offset value.

Balance variable	Mean results (SD)	95 % CI	b	T	p
BESS	12.4 (5.7) points	[11.3-13.5]	2.195	5.489	0.022
YBT anterior right	71.1 (5.9) %	[69.9-72.3 %]	−0.022	5.386	0.023
YBT anterior left	71.7 (5.9) %	[70.6-72.9 %]	−0.024	6.149	0.015
YBT posteromedial right	108.5 (6.7) %	[107.2-109.8 %]	−0.011	1.204	0.275
YBT posteromedial left	107.7 (7.2) %	[106.2-109.1 %]	−0.029	5.607	0.020
YBT posterolateral right	103.2 (7.6) %	[101.7-104.7 %]	−0.015	1.317	0.256
YBT posterolateral left	106.0 (7.0) %	[104.6-107.4 %]	−0.015	1.926	0.168

BESS = Balance Error Scoring System, YBT = Y-Balance Test; SD = standard deviation; CI = confidence interval.

results. Besides maturity, anthropometric characteristics and balance ability, postural control is in the end also influenced by strength, acute or chronic injuries like chronic ankle instability, anterior cruciate ligament reconstruction or patellofemoral pain syndrome as the flexibility of the hip, knee or ankle [9,24]. For example, decreased SEBT reach distances could have been observed in subjects with chronic ankle instability or anterior cruciate ligament reconstruction [9]. In addition, postural control is influenced by concussion and fatigue. These conditions worsen balance, shown by higher BESS scores [20]. In the current study, none of these factors have been considered All the same, the present study is, to the best of our knowledge, the first to show that there are significant associations between biological maturity and static as well as some dynamic postural control variables.

Based on our results that adolescents situated in the maturity process have deficits in postural control, some practical implications can be drawn. Youth sport coaches should focus on improvements of static and dynamic balance control. Effective interventions in this population could be neuromuscular training programs embedded in regular warm up procedures during sports practice. It has been shown that either balance training alone or multi-intervention programs, including plyometric, balance, strength and agility exercises might reduce lower extremity injury risk [30]. In addition, to prevent unnecessary and avoidable injuries following competition between unequally mature athletes, to facilitate the coaches training designs and to ensure competitive equality, categorization of youth sport teams should take place based on the criterion of biological age [15,26].

For further investigations regarding the subject of biological maturity and postural control, the current studies' limitations can serve as pieces of advice what can be refined in studies dealing with biological maturity and static and dynamic balance. A longitudinal study approach would certainly help to increase the knowledge about the phenomenon of adolescent motor awkwardness in association with postural control [2].

Based on the possibility of a large discrepancy between chronological and biological age [2,25], the call for changes regarding the classification practice in youth sports receives support from the current studies' results. As there is an association between biological maturity and postural control which may contribute to the increased injury risk [7,8], youth athletes should undergo special training programs in critical periods of maturation, for example the adolescent growth spurt.

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