Journal of Shahrekord University of Medical Sciences
doi: 10.34172/jsums.2023.657 2023;25(2):x-x http://j.skums.ac.ir

Original Article

Is there any association between school-aged children's maturity and movement efficiency?

Sajad Bagherian[1*], Khodayar Ghasempoor[2], Mohammad Hossein Alizadeh[3]

[1]Department of Sport Sciences, Shahrekord University, Shahrekord, Iran
[2]Department of Physical Education and Sport Sciences, Technical and Vocational University, Tehran, Iran
[3]Faculty of Sport Sciences, University of Tehran, Tehran, Iran

*__Corresponding Author:__ Sajad Bagherian, Tel:+989133821436, Email: s.bagherian@sku.ac.ir

Abstract

Background and aims: Significant biological changes occur during growth spurts, particularly at pre/post-maturity stages. It seems that such changes are associated with neuromuscular patterns, with considerable differences in functional movements performed by growing boys and girls through the process of maturation. The purpose of the study was to investigate the association between school-aged children's maturity and their ability to move efficiently.

Methods: A cross-sectional observational study was conducted on 700 healthy school-aged children, aged 8–17 years, who were randomly selected and divided into ten groups of 35 girls and ten groups of 35 boys. We used maturity offset prediction equations and the Fusionetics tests to evaluate the maturity and movement efficiency, respectively. Furthermore, the relationship between maturity and Fusionetics scores was examined using Spearman's rank correlation coefficient ($P \leq 0.05$).

Results: The findings of the study demonstrated that there is a moderate association between maturity and Fusionetics scores (boys r=0.34, $P=0.001$ and girls r=0.44, $P=0.001$). The results also estimated that more mature children gain better Fusionetics scores (r=0.45; $P=0.001$).

Conclusion: It seems that maturity is correlated with movement efficiency, and more mature children can obtain better Fusionetics scores. Future research is needed to track maturity-related variations in functional movement scores in adolescence.

Keywords: Movement proficiency, Maturity, Functional movement, Peak height velocity, Fusionetics

Received: Marth 26, 2022, Accepted: June 6, 2022, ePublished: December 10, 2022

Introduction

Physical activity (PA) is in great demand among adolescents today, and it is linked to several health advantages (1). Appropriate quantities of PA help develop healthy musculoskeletal tissues (e.g., muscles, bones, and joints), neuromuscular function (e.g., movement control and coordination), a healthy cardiovascular system (lungs and heart), and a healthy body weight (2). Despite the well-known benefits of PA, the majority of children and adolescents around the world do not meet the minimal PA recommendations (3). In the literature, it is commonly believed that boys are more active than girls during the maturation years as measured by a variety of tools (4,5). PA declines with age in both boys and girls according to the research findings (4). However, a few studies have investigated the accounting of maturation in PA studies in boys and girls. For example, pubertal development could be one reason for the drop in PA levels among adolescent girls (i.e., biological age or maturity). Two previous studies in this domain have accordingly found a decreasing trend in self-reported (6) and objectively measured activities (4). The amount of PA is increasing with biological age among adolescent girls, which is opposed to chronological aging as an index of the passage of human time, while biological aging refers to the underlying aging processes at the biological level. However, once the impact of pubertal development on PA is considered, the timing of pubertal or biological maturity may become more important.

The biological maturity of an individual at the time of observation is referred to as maturity status (early, on time, late, mature based on skeletal age, and puberty stage), whereas the time of maturity refers to the ages at which specific maturational events occur such as ages at peak height velocity (PHV) and menarche (7). Adolescent growth and functional performance are strongly linked to biological maturation, leading to large performance discrepancies across boys who are chronologically the same age (8). Adolescents of different biological ages have different timing and speed of maturation (7). Biological maturity is a critical component for reaching a higher level of performance (9). As a result, when assessing teenage physical fitness, it is important to figure out their biological age (10). In age-matched adolescents, maturity has a temporary effect on performance tests, meaning that more mature individuals perform better on the same test

© 2023 The Author(s); Published by Shahrekord University of Medical Sciences. This is an open-access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

than their less mature counterparts (11). Consequently, when evaluating these findings, it is important to consider an individual's maturity level and how it relates to biological age rather than to chronological age (7). Failure to consider an individual's maturity level leads to a bias in talent selection in favor of the early mature individuals, which is why coaches prefer early mature children as a result of their physical advantage over peers (7).

Individuals' adolescent growth spurts differ greatly in terms of timing, speed, and duration (4). During a growth spurt, various changes in body dimensions and physical proportions happen that may affect physical performance. Previous research has also highlighted the relevance of efficient movement skill competence in young athletes for safe and efficient long-term physical performance (12). Young athletes, for example, may be predisposed to injury due to inadequate neuromuscular control and inefficient movement patterns during landing and cutting movements (13). It has also been claimed that age-related motor skill deficiencies may cause a proficiency barrier, preventing progress toward acquiring more complicated movement patterns (14). Many physical aspects that affect performance testing such as strength and endurance increase after the peak adolescent growth spurt (7). As a result, PHV was offered as a useful reference for changes in body dimensions and physical proportions during puberty, the period of most rapid growth (15). While research revealed a possible relation between movement efficiency and injury prevention and/or reduction, the link between movement skill competence and maturity assessments in children and adolescents is still unknown (15). Therefore, assessing movement efficiency should be considered an important component of youth physical development programs. The major goal of this study was to find out if there is an association between maturity and movement efficiency (i.e., movement proficiency) in school-aged children. Based on previous studies, we hypothesized that there are significant relationships between maturity and movement efficiency.

Materials and Methods

Participants

A total of 700 healthy children aged 8-17 years were randomly (sealed envelopes) selected from various schools in the province of Chaharmahal and Bakhtiari, and 35 girls and 35 boys of all ages entered the study. The ethics approval was also obtained from the Ethics Committee at the University of Tehran. All students were medically cleared to participate in this study based on the school physician's report and lacked any injury or diagnosed learning difficulty that would interfere with movement (e.g., developmental coordination disorder). Written informed consent was also obtained from the participant's parents or guardians.

Procedures

The students were tested in their chronological age group based on their chronological (year of birth) age. Height was also measured to the nearest 0.1 cm (Seca 213), and weight was determined to the nearest 0.1 kg (Seca 803) by trained movement scientists. Age groups were further divided based on one-year intervals from 8 to 17 years. All the data were collected under standard conditions within four-week periods. The students were then transported in small groups from their school to a public sports complex where they were measured and assessed in an indoor practice facility.

Biological maturation

Predicted maturity offset, which is defined as the time before or after PHV (i.e., the adolescent growth spurt in height), is an indicator in which chronological age at prediction minus offset gives an estimate of age at PHV (15). As a result, the age of PHV was estimated using a non-invasive practical method (10). A PHV assessment was accordingly performed based on the method proposed by Moore et al (16), which may estimate how far away an individual was from the PHV age in years (Figure 1). Interactions between age and height were included in the model. Using these data, the maturity offset prediction equation formula was used for girls in years -7.709133 + (0.0042232 x [age x body height]) and boys in years -7.999994 + (0.0036124 x [age x body height]). When compared to the original equations, this new equation had less fluctuation (15) and was effective for more correctly assessing maturity. Furthermore, since PHV had more consistency in biological classification, it was believed to be an ideal measure to group individuals within a common maturation marker (10). Biological maturation was considered the difference of predicted ages minus observed ages at PHV (10).

Movement efficiency

The Fusionetics™ movement efficiency (ME) Test, a new measure of functional movement quality, was recently published (17). Fusionetics, LLC (Milton, GA) developed this assessment, which is part of the Fusionetics™ Human Performance System. The ME test has seven sub-tests that require a person to perform various movement patterns (18). The ME Test, on the other hand, is assessed based on the existence of common movement compensations during each subtest. The Fusionetics™ Human Performance System generates a 0–100 (worst–best) score based on movement compensations observed throughout the assessment as well as an ME Test score for each individual sub-test, using computer-based proprietary algorithms (17).

Fusionetics, LLC provides guidelines for conducting the ME Test (Table 1). In summary, all of the ME Test participants wore sports clothing and no shoes. The following is the order in which each participant finished each sub-test: 1-leg squat, 2-leg squat with a heel lift, 2-leg squat with a heel lift, 2-leg squat with a heel lift, push-up, shoulder, trunk, and cervical movements.

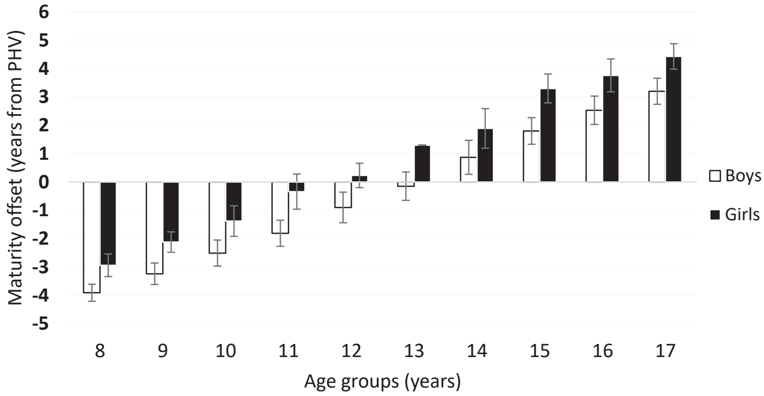

Figure 1. Age groups and maturity offset

Participants were given 3-5 trials of each sub-test with the most proficient trial (i.e., the one with the fewest compensations) being used to score each sub-test (18-20). Each sub-test was assessed in real-time using a binomial (yes/no) method based on a standard set of movement compensations observed throughout the sub-test (Table 1). Across all sub-tests, the ME test scores a total of 60 compensations. The binomial data were entered into the Fusionetics^{TM} Human Performance System after each sub-test was graded. Using a proprietary algorithm, this online platform determines an ME Test score for the overall assessment (i.e., the overall ME test score) as well as an ME Test score for each individual sub-test. These ME test results represent interval-level data in the range 0-100, namely, from the worst to the best (19,20).

The Fusionetics ME Test examines movement quality using seven separate tasks, three of which focus on the lower extremity similar to the functional movement screen (FMS) (17). The ME Test scores may be sensitive to changes in functional movement quality as a result of various corrective exercise interventions that address the specific movement compensations identified during the sub-tests due to the use of discrete individual movement compensations in the scoring algorithms (17). Since the FMS clinical value in tracking changes in movement quality has been questioned (21), the ME Test may be a more valid and/or therapeutically relevant measure of functional movement quality.

The research team completed both online instruction and repeated scoring of 10 pilot participants until an acceptable degree of reliability was obtained before beginning this study. It should be noted that the Fusionetics had excellent intra-rater test-retest reliability as a test for functional movement quality (17).

Statistical analyses

The normality of the distribution was not verified using the Shapiro–Wilk test ($P < 0.05$). Spearman's rank correlation coefficient was used to determine the association between all of the Fusionetics and maturity offset prediction scores. Fusionetics scores were compared between boys and girls across age groups using the Mann-Whitney U test.

A correlation value of less than 0.4 was regarded as weak, between 0.40–0.69 was considered moderate, and more than 0.70 was considered strong. The SPSS Statistics software version 22 (SPSS Inc., IBM Company, N.Y., USA) was used to conduct the statistical analysis. A priori statistical significance was defined at $P < 0.05$.

Results

Table 2 shows the demographic data of the participants, which include age, weight, height, and body mass index. Moreover, the predicted PHV from maturity offset by age group is summarized in Figure 1. Figure 1 indicates that girls over the age of 12 and boys over the age of 14 have a positive maturity offset (post-PHV), while both boys and girls under these ages have a negative maturity offset (pre-PHV). This means that girls aged 12 and boys aged 14 received their maximum PHV. In terms of age groups and Fusionetics scores, Figure 2 indicates that both boys and girls improved their Fusionetics scores as they grew older.

Table 3 also depicts the Fusionetics scores for each task as well as the total Fusionetics scores for all seven tasks by age group. In almost all age groups, as shown in Table 3, girls scored higher on Fusionetics in almost all of the tasks. Girls had considerably higher Fusionetics scores than boys did at the age of 12 (i.e., girls' PHV) in various tasks, including the double leg squat, double leg squat with a heel raise, single leg squat, and overall score. At the age of 14 (i.e., boys' PHV), however, boys did not perform better than girls. In this study, a significant correlation was observed between maturity and Fusionetics scores (Table 4). The coefficient of determination (R2) indicated that 20% of the variance in the total Fusionetics scores was explained by maturity.

Discussion

The primary goal of this study was to find out if there is an association between maturity and movement efficiency in school-aged children. The findings of the investigation demonstrated a strong link between maturity and movement efficiency. To explore movement efficiency in school-aged children, Fusionetics was employed,

Table 1. Movement efficiency test checklist

Test/Movement	Starting position/movement instructions	Checkpoint evaluation/observation criteria for fail
2-Leg squat	✓ Feet shoulder-width apart ✓ Toes pointing straight ahead ✓ Arms extended directly overhead ✓ Perform 5-15 squats as if sitting in a chair ✓ Evaluate: Front, side, and back view	✓ Foot turns out: Any lateral deviation from starting position ✓ Foot flattens: 5th Metatarsal is elevated and/or toes lift ✓ Knee moves in: Mid-patella moves medial of 1st toe ✓ Knee moves out: Mid-patella moves lateral of 5th toe ✓ Excessive forward lean: Inability to maintain a torso parallel to the tibia ✓ Low back arches: Increased lumbar extension from starting position Low back rounds: Increased lumbar flexion from starting position (occurring before 90° of hip flexion)
2-Leg squat with a heel lift	✓ Elevate heels approximately 2 ✓ Feet shoulder-width apart ✓ Toes pointing straight ahead ✓ Arms extended directly overhead ✓ Perform 5-15 squats as if sitting in a chair ✓ Evaluate: Front, side, and back view	✓ Arms fall forward: Inability to maintain a straight line as an extension ✓ of the torso ✓ Heel of foot lifts (2-Leg squat only): Inability to keep heels in contact ✓ with the floor ✓ Asymmetrical weight shift: Record the side shifting towards
1-Leg squat	✓ Toes pointing straight ahead ✓ Athlete balances on 1-leg ✓ Place hands on hips ✓ Perform 5 squats per leg ✓ Evaluate: Front view	✓ Foot flattens: 5th Metatarsal is elevated and/or toes lift ✓ Knee moves in: Mid-patella is medial of 1st Toe ✓ Knee moves out: Mid-patella is lateral of 5th Toe ✓ Uncontrolled trunk: Inability to maintain torso parallel to the tibia ✓ and/or any change from starting/neutral position ✓ Loss of balance: Two or more touches with the non-involved foot and/or ✓ any hopping to retain balance
Push-up	✓ Assume a push-up position w/ hands outside shoulders (thumb to armpit) and even with chest ✓ Eyes looking toward the ground ✓ Perform 5-10 push-ups ✓ Lower chest to within 3-5 inches from the ground ✓ Evaluate: Side view	✓ Head moves forward: Increased cervical extension and/or flexion ✓ Scapular winging: Any asymmetry or excessive elevation of the inferior ✓ pole and/or medial border of the scapula ✓ Low back arches/stomach protrudes: Inability to maintain rigid ✓ trunk-hip-leg body posture throughout the movement and/or ✓ abdominal contents distend ✓ Knees bend: Inability to maintain a straight-leg orientation
Shoulder movements	✓ Stand with heels, butt, shoulders, back of the head against a wall ✓ Feet hip-width apart, arms by sides • Flexion: Raise arm straight up, touch thumb to wall overhead • Internal rotation: Shoulders abducted at 90°, elbows at 90°, rotate shoulder taking hand forward toward lateral mid-line of body • External rotation: Shoulders abducted at 90°, elbows at 90°, rotate shoulder touching back of the wrist to wall. • Horizontal abduction: Hands together in front of the body, reach back of the hand to the wall ✓ Evaluate: Front and side view ✓ Perform 1-arm at a time	✓ Flexion: Inability to touch thumb to wall Inability to keep elbow fully extended Inability to keep head against the wall Early/excessive shoulder elevation Any movement in unwanted planes Any change in lumbar positioning ✓ Internal rotation: • Inability to get wrist to lateral mid-line of the body • Elbow flexes or extends during movement • Inability to keep head against the wall • Shoulder protraction away from the wall ✓ External rotation: • Inability to get back of the wrist to wall and/or • compensates w/ wrist extension so fingertips touch the wall • Elbow flexes or extends during movement • Inability to keep head against the wall • Early/excessive shoulder elevation • Any change in lumbar positioning ✓ Horizontal abduction: • Inability to keep head against the wall • Elbow flexes during movement • Early/excessive shoulder elevation • Any change in lumbar positioning • Trunk rotates to the involved side
Trunk movements	✓ Stand with heels, butt, shoulders, and back of the head against a wall ✓ Feet hip-width apart, arms by sides • Lateral flexion: Side bend and slide a hand down outside of the leg to the lateral aspect of the knee ✓ Rotation: Athlete steps away from wall and places hands across shoulders • Rotation: Rotate the upper body in one direction as far as possible ✓ Evaluate: Fonts and side view ✓ Perform movements in each direction	✓ Lateral flexion: • Inability to reach fingers to the lateral joint line • Knee flexes on the involved side • Inability to maintain a neutral pelvis • The opposite heel lifts off the floor • Any movement in unwanted planes ✓ Rotation: • Early movement of the pelvis to get more rotation • Low back flexes/extends and/or laterally flexes • Inability to align anterior acromion to the umbilicus
Cervical movements	✓ Feet hip-width apart, arms by sides ✓ Head in a neutral position • Lateral flexion: Tip head, moving ear toward the shoulder • Rotation: Rotate head and look over shoulder ✓ Evaluate: Front and side view ✓ Perform movements in each direction	✓ Lateral flexion: • Any movement in unwanted planes • Inability to bring ear to practitioner's fingers • Asymmetrical lateral flexion ✓ Rotation: • Any movement in unwanted planes • Inability to get the middle of the chin (cleft) to align with the anterior • acromion

Table 2. Characteristics of school-age children

Age group	Age (year)		Weight (kg)		Height (cm)		BMI (kg/m²)	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
+8	8.45±0.50	8.54±0.50	26.5±3.9	28.1±7.7	134.3±5.1	132.3±6.1	14.5±1.9	15.9±3.6
	(*P*=0.476)		(*P*=0.528)		(*P*=0.183)		(*P*=0.123)	
+9	9.57±0.50	9.60±0.49	31.3±7.8	31.4±8.9	138.2±6.5	138.1±6.1	16.3±3.1	16.1±3.4
	(*P*=0.810)		(*P*=0.525)		(*P*=0.663)		(*P*=0.256)	
+10	10.57±0.55	10.45±0.50	36.1±10.9	38.1±9.9	144.1±4.8	143.1±8.2	17.5±4.7	17.9±3.2
	(*P*=0.415)		(*P*=0.323)		(*P*=0.809)		(*P*=0.316)	
+11	11.48±0.50	11.60±0.49	37.4±8.9	39.3±9.7	149.3±6.2	150.6±7.9	16.4±3.1	16.9±3.1
	(*P*=0.341)		(*P*=0.437)		(*P*=0.655)		(*P*=0.176)	
+12	12.51±0.50	12.28±0.51	46.1±12.4	43.2±8.9	157.2±9.1	154.3±5.4	18.5±4.2	18.5±3.7
	(*P*=0.226)		(*P*=0.125)		(*P*=0.031)		(*P*=0.476)	
+13	13.40±0.49	13.62±0.54	52.2±11.6	53.4±14.2	162.3±7.1	157.1±7.8	19.7±4.1	21.6±4.8
	(*P*=0.081)		(*P*=0.668)		(*P*=0.006)		(*P*=0.039)	
+14	14.65±0.63	14.45±0.50	58.2±12.4	54.3±14.2	166.1±7.9	157.5±10.9	20.9±3.7	21.6±4.5
	(*P*=0.211)		(*P*=0.059)		(*P*<0.001)		(*P*=0.031)	
+15	15.65±0.48	15.62±0.54	60.1±11.8	60.5±13.4	173.2±5.2	167.2±4.9	19.9±3.4	21.6±4.3
	(*P*=0.744)		(*P*=0.491)		(*P*<0.001)		(*P*=0.043)	
+16	16.48±0.50	16.40±0.55	66.1±11.9	59.2±11.5	177.2±6.7	166.4±6.3	20.9±3.6	21.5±4.4
	(*P*=0.744)		(*P*=0.491)		(*P*<0.001)		(*P*=0.036)	
+17	17.48±0.50	17.40±0.49	68.3±13.3	58.1±10.3	177.1±5.9	165.1±5.2	21.5±3.6	21.1±3.3
	(*P*=0.474)		(*P*<0.001)		(*P*<0.001)		(*P*=0.231)	

Note. BMI: Body mass index.
P values indicate differences between boys versus girls (Mann–Whitney U test, $P \leq 0.05$).

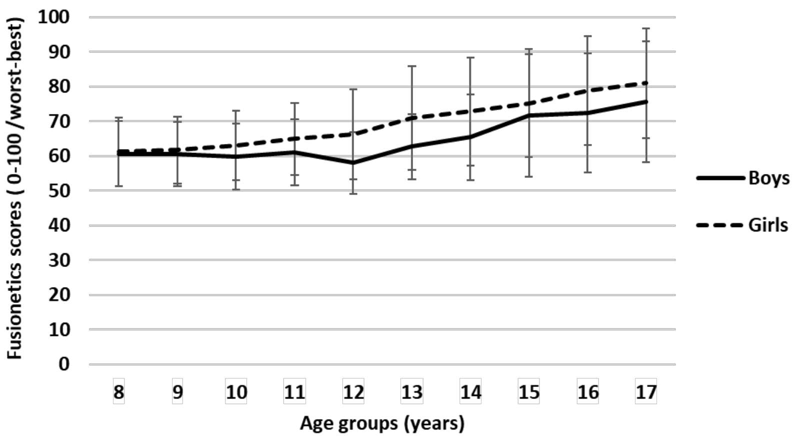

Figure 2. Age groups and Fusionetics scores

which was previously used in other studies to determine movement efficiency (19,20). The Fusionetics Scoring System is a novel evidence-based assessment that claims to capture risk indicators that have been ignored by previous assessments due to their flaws (19,20). It contains tests to uncover biomechanical flaws that have been found to be strong injury predictors (17).

The findings reveal a link between FMS scores and maturity; in this regard, they are consistent with prior studies (12,22-24). These findings also suggested a relationship between maturity and movement efficiency. Understanding the effects of growth and development on sports performance and injuries is extremely critical. Additionally, gender-related physical and physiological variations that arise as a result of development must be identified as these changes may help explain gender disparities in strength, power, and coordination following puberty (25). Talent development programs should therefore maximize individual development.

Furthermore, this study showed that growth spurts in girls and boys can happen at ages 12 and 14, respectively (Figure 1). Likewise, most of the previous studies had reported these ages (12 vs. 14) for the growth spurts of boys and girls (7,15,26). Accordingly, maturity assessment can

Table 3. Fusionetics Scores During Each Task and Total Fusionetics Scores of all Seven Tasks by Age Group

Age Group	Double leg squat		Double leg squat with heel lift		Single leg squat		Push-up	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
8	34.73±22.45	31.36±23.75	42.32±29.05	34.32±26.66	36.19±20.10	34.05±21.71	46.86±13.67	46.86±14.51
	(*P*=0.616)		(*P*=0.193)		(*P*=0.666)		(*P*=0.850)	
9	33.05±23.80	31.46±23.82	36.82±27.45	35.46±27.50	34.29±22.30	34.76±23.61	48.00±14.71	46.86±14.51
	(*P*=0.677)		(*P*=0.797)		(*P*=0.943)		(*P*=0.631)	
10	26.51±22.44	33.81±23.14	30.06±25.96	36.16±25.14	34.29±23.81	38.57±25.09	44.57±10.94	46.86±14.51
	(*P*=0.215)		(*P*=0.474)		(*P*=0.512)		(*P*=0.658)	
11	30.86±24.65	33.62±19.74	33.27±26.91	38.82±24.23	31.91±22.18	47.14±24.66	48.00±15.49	42.29±8.08
	(*P*=0.686)		(*P*=0.237)		(*P*=0.007)		(*P*=0.086)	
12	21.27±24.37	36.54±25.06	20.25±21.42	45.05±30.10	22.86±15.70	47.14±26.58	46.86±15.30	45.71±15.77
	(*P*=0.017)		(*P*<0.001)		(*P*<0.001)		(*P*=0.745)	
13	34.89±27.03	43.18±29.50	29.97±21.64	50.22±31.50	27.14±18.83	53.81±29.73	53.71±19.26	50.86±21.88
	(*P*=0.603)		(*P*<0.001)		(*P*<0.001)		(*P*=0.441)	
14	32.67±25.06	46.83±30.66	40.51±31.60	55.30±33.13	42.86±28.09	57.14±31.12	48.00±18.91	56.00±25.58
	(*P*=0.063)		(*P*=0.049)		(*P*=0.053)		(*P*=0.143)	
15	49.40±35.0	52.95±30.27	50.22±34.93	60.48±32.53	46.67±34.01	63.33±32.79	62.29±25.56	62.29±27.77
	(*P*=0.496)		(*P*=0.158)		(*P*=0.044)		(*P*=0.953)	
16	54.12±34.47	60.16±30.35	50.60±34.23	66.70±31.25	42.38±35.09	70.00±32.03	69.71±23.45	69.71±27.17
	(*P*=0.413)		(*P*=0.016)		(*P*=0.002)		(*P*=0.873)	
17	56.86±34.16	64.45±30.01	59.49±34.37	70.89±30.10	50.95±35.22	73.33±31.36	70.86±23.44	73.14±26.98
	(*P*=0.191)		(*P*=0.116)		(*P*=0.011)		(*P*=0.650)	
Age Group	**Shoulder movement**		**Trunk/lumbar spine movement**		**Cervical spine movements**		**Total score**	
	Boys	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**	**Boys**	**Girls**
8	92.86±11.46	96.43±8.88	82.86±38.24	91.43±28.40	82.86±38.24	91.43±28.40	60.64±9.36	61.22±9.81
	(*P*=0.148)		(*P*=0.288)		(*P*=0.288)		(*P*=0.519)	
9	94.29±10.65	97.14±8.07	85.71±33.37	90.00±26.57	88.57±32.28	94.29±23.55	60.59±9.27	61.69±9.71
	(*P*=0.208)		(*P*=0.690)		(*P*=0.397)		(*P*=0.501)	
10	95.71±9.56	97.14±8.07	90.00±26.57	90.00±26.57	94.29±23.55	94.29±23.55	59.86±9.48	63.05±9.93
	(*P*=0.498)		(*P*=1.000)		(*P*=1.000)		(*P*=0.208)	
11	97.14±8.07	97.14±8.07	91.43±25.68	90.00±26.57	94.29±23.55	94.29±23.55	60.99±9.52	64.91±10.27
	(*P*=1.000)		(*P*=0.739)		(*P*=1.000)		(*P*=0.035)	
12	100.00±0	97.14±8.07	100.00±0	90.00±26.57	100.00±0	94.29±23.55	58.00±8.84	66.17±12.95
	(*P*=0.041)		(*P*=0.021)		(*P*=0.021)		(*P*=0.008)	
13	100.00±0	98.57±5.89	100.00±0	94.29±16.14	100.00±0	100.00±0	62.70±9.44	70.90±14.95
	(*P*=0.154)		(*P*=0.041)		(*P*=1.000)		(*P*=0.009)	
14	98.57±5.05	97.86±6.42	97.14±10.09	95.71±12.84	97.14±11.78	97.14±11.78	65.51±12.35	72.81±15.58
	(*P*=0.676)		(*P*=0.676)		(*P*=1.000)		(*P*=0.065)	
15	97.86±7.10	97.14±6.84	100.00±0	91.43±17.09	100.00±0	94.29±16.14	71.68±17.57	75.25±15.49
	(*P*=0.347)		(*P*=0.003)		(*P*=0.041)		(*P*=0.155)	
16	100.00±0	97.14±6.84	100.00±0	90.00±18.39	100.00±0	94.29±16.14	72.39±17.11	78.88±15.75
	(*P*=0.011)		(*P*<0.001)		(*P*=0.041)		(*P*=0.021)	
17	100.00±0	97.14±6.84	100.00±0	90.00±18.39	100.00±0	94.29±16.14	75.62±17.35	80.99±15.75
	(*P*=0.011)		(*P*<0.001)		(*P*=0.041)		(*P*=0.059)	

Note. All are scored 0-100 (worst-best). *P*-values indicate differences between boys versus girls (Mann–Whitney U test, $P \leq 0.05$).

have specific applications in the classification of children for sports during the adolescence stage. Individuals of the same chronological age can have a wide range of somatic and biological growth, which is most noticeable during adolescent growth spurts (27). It is worth noting that the rate of growth in stature is maximum during the first year of life, and gradually decreases until the start of the adolescent growth spurt (12 years of age in boys). The

Table 4. Correlation of Maturity Offset and Fusionetics Scores

		Double leg squat		Double leg squat with a heel lift		Single leg squat		Push-up		Shoulder movement		Trunk/ lumbar spine movement		Cervical spine movements		Total score	
		Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Maturity offset	Correlation	0.23	0.35	0.15	0.40	0.12	0.43	0.36	0.38	0.27	0.23	0.24	0.125	0.20	0.061	0.34	0.44
	P value	<0.001	<0.001	0.004	<0.001	0.023	<0.001	<0.001	<0.001	<0.001	0.668	<0.001	0.019	<0.001	0.254	<0.001	<0.001

growth rate increases throughout the spurt and reaches a peak (i.e., PHV) in males at the age of 14, then gradually decreasing and eventually ceasing with the attainment of adult size (7).

The model of the functional, morphological, anatomical, and biochemical status of the organism, its characteristics for a given chronological period, and the imbalance in biological and chronological maturity are all used to define biological maturity, as seen in the rate of changes that characterize stages of development (28). Anthropometric body measurements can also be used to predict biological maturity in young persons (15). The anthropometric method is based on the PHV phenomenon, which is a somatic factor that indicates when a person is approaching full maturity (15). Furthermore, the approach is widely acknowledged as a simple diagnostic procedure for determining biological maturity in both male and female adolescents, and it can be used to estimate the final height in the same way (28). Changes in limb length and muscle mass linked with pubertal growth and maturation alter boys' strength, power, stride length, and stride frequency stability, implying a potential maturity-related component of speed (7). The biological maturation status of young athletes is an important issue to consider while analyzing them because it may influence their injury risk or test performance (29). Most individual components of Fusionetics scores in this study were significantly correlated with maturity offset (see Table 4), illustrating the importance of specific deficiencies in restricting children's physical performance.

In terms of the Fusionetics scores, the study results suggested that the movement efficiency scores increase in boys (20%) and girls (32%) based on the growth rates. Fusionetics movement efficiency is also measured by calculating an overall score out of 100 based on each individual's compensation for criteria movement (17). With regard to the Fusionetics algorithms, good movers score 75-100, moderate ones score 50-75, and poor movers score below 50 (17). Fusionetics movement efficiency is more sensitive than other screening methods because it assesses global movement patterns based on normal standards rather than on bilateral dysfunction comparisons (17,30). In the present study, the mean Fusionetics movement efficiency scores started at 60 in 8-year-old children and gradually increased in older children until scores of 80 in girls and 75 in boys were obtained in 17-year-olds. Overall, girls tended to have higher Fusionetics scores than boys.

While research reveals a link between movement skill competence and injury avoidance and/or decrease in children, the link between movement skill proficiency and physical performance measures in children is less obvious, and the results are equivocal where such data exists (31). As evidenced by a higher rate and risk of hamstring injury in elite junior soccer players with isokinetic strength imbalance, muscle imbalance is a significant injury risk factor for children (32). In young athletes, for example, poor neuromuscular control and insufficient movement patterns during landing and cutting movements may increase the risk of injury (13). In this respect, van der Slet al conducted a study in which differences in injury occurrence in talented pubertal soccer players within various phases of maturation (i.e., before, during, and after PHV) were examined. It had also been concluded that the given players were more vulnerable to traumatic injuries during PHV (33), and this might be even true for later-maturing cases. Examining gender differences in neuromuscular performance during growth and maturation may help identify risk factors that lead to gender differences in injury rates and may aid to develop injury prevention strategies as pubertal stages are linked to both the occurrence and type of sports injury (34).

The findings of the present study could have far-reaching consequences in practice. Academies should regularly assess the maturity level of young athletes in order to identify those who are at a higher risk of injury. At-risk players should also have injury prevention strategies adopted, and coaches and players should be made aware of their increased sensitivity. Examples of such strategies include motor skill improvement, balance activities, core strength activities, and reduced loading (35).

There are a few potential limitations to this study that should be noted. The assessment of maturation using PHV-predicted age was one of the study's limitations. However, since biological maturation could not be directly evaluated, it was represented by somatic maturation using Moore et al' s prediction equation. Moreover, menarche status (in females) was not examined, and previous research has suggested that menarche is a late adolescent event that can alter the study's conclusions. When using the prediction equation for potentially early-maturing populations, however, some caution is advised. In terms of practical application, the prediction equation could be a reliable, non-invasive, and time-saving method for assessing biological maturity in children. Furthermore, no data on sports participation or injuries were gathered. It is a relatively small sample size, and the reliability of Fusionetics data should be validated in children and adolescents. Future research should thus attempt to overcome some limitations of this study by quantifying and understanding how age is partially correlated with the maturity groups and movement efficiency and how training load and interventions can affect the relationship between maturity status and maturity timing.

The major limitations of all formulae used to predict years from the age at PHV (maturity shift) or age at PHV are the same (36,37). When used at a given time point, the accelerated maturity timing of teenage male athletes and the relatively limited range of projected age at PHV may limit its utility and effectiveness in talent identification and development programs (38,39).

Conclusion

This is the first study that looked into the link between maturity and movement efficiency. Maturity offset seemed to be correlated with movement efficiency, and more mature children showed better movement scores. Future research should thus explain the role of the interaction between maturity and Fusionetics scores on injury risk prediction. As a result, recognizing potential changes in functional tests during the maturation process might be a target for planning exercises. Accordingly, more research needs to be conducted on the causes of these differences. Given that the findings of functional tests may be influenced by maturity as they are perceived, reflecting on biological age rather than chronological age will be more accurate.

Acknowledgments

The authors hereby extend their gratitude to the school-age children who participated in this study and the research assistants contributing to data collection.

Author Contributions

Conceptualization: Sajad Bagherian, Khodayar Ghasempoor, Mohammad Hossein Alizadeh.
Data curation: Sajad Bagherian, Khodayar Ghasempoor, Mohammad Hossein Alizadeh.
Formal Analysis: Sajad Bagherian.
Funding acquisition: Sajad Bagherian.
Investigation: Sajad Bagherian, Khodayar Ghasempoor, Mohammad Hossein Alizadeh.
Methodology: Sajad Bagherian, Khodayar Ghasempoor, Mohammad Hossein Alizadeh.
Project administration: Sajad Bagherian.
Resources: Sajad Bagherian.
Software: Sajad Bagherian.
Supervision: Sajad Bagherian, Khodayar Ghasempoor, Mohammad Hossein Alizadeh.
Validation: Sajad Bagherian, Khodayar Ghasempoor, Mohammad Hossein Alizadeh.
Visualization: Sajad Bagherian, Khodayar Ghasempoor.
Writing – original draft: Sajad Bagherian, Khodayar Ghasempoor.
Writing - review & editing: Sajad Bagherian, Khodayar Ghasempoor, Mohammad Hossein Alizadeh.

Conflict of Interests

The authors have no conflict of interests associated with the material presented in this paper.

Ethical Approval

This study protocol was approved by the Ethics Committee of the University of Tehran (IR.UT.SPORT.REC.1398.012).

Funding/Support

This study has been financially supported by the research deputy of Shahrekord University. The grant number was GRD34M1636.

References

1. Bagherian S, Mardaniyan Ghahfarrokhi M, Banitalebi E. Effect of the COVID-19 pandemic on interest in home-based exercise: an application of digital epidemiology. Int J Epidemiol Res. 2021;8(1):47-53. doi: 10.34172/ijer.2021.08.
2. Warburton DER, Bredin SSD. Health benefits of physical activity: a systematic review of current systematic reviews. Curr Opin Cardiol. 2017;32(5):541-56. doi: 10.1097/hco.0000000000000437.
3. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. Lancet Child Adolesc Health. 2020;4(1):23-35. doi: 10.1016/s2352-4642(19)30323-2.
4. Sherar LB, Esliger DW, Baxter-Jones AD, Tremblay MS. Age and gender differences in youth physical activity: does physical maturity matter? Med Sci Sports Exerc. 2007;39(5):830-5. doi: 10.1249/mss.0b013e3180335c3c.
5. Moore SA, Cumming SP, Balletta G, Ramage K, Eisenmann JC, Baxter-Jones ADG, et al. Exploring the relationship between adolescent biological maturation, physical activity, and sedentary behaviour: a systematic review and narrative synthesis. Ann Hum Biol. 2020;47(4):365-83. doi: 10.1080/03014460.2020.1805006.
6. Thompson A, Baxter-Jones AD, Mirwald RL, Bailey DA. Comparison of physical activity in male and female children: does maturation matter? Med Sci Sports Exerc. 2003;35(10):1684-90. doi: 10.1249/01.mss.0000089244.44914.1f.
7. Malina RM, Bouchard C, Bar-Or O. Growth, Maturation, and Physical Activity. Human Kinetics; 2004.
8. Malina RM, Cumming SP, Kontos AP, Eisenmann JC, Ribeiro B, Aroso J. Maturity-associated variation in sport-specific skills of youth soccer players aged 13-15 years. J Sports Sci. 2005;23(5):515-22. doi: 10.1080/02640410410001729928.
9. Ribeiro Junior DB, Werneck FZ, Oliveira HZ, Panza PS, Ibáñez SJ, Vianna JM. From talent identification to Novo Basquete Brasil (NBB): multifactorial analysis of the career progression in youth Brazilian elite basketball. Front Psychol. 2021;12:617563. doi: 10.3389/fpsyg.2021.617563.
10. Kozieł SM, Malina RM. Modified maturity offset prediction equations: validation in independent longitudinal samples of boys and girls. Sports Med. 2018;48(1):221-36. doi: 10.1007/s40279-017-0750-y.
11. Philippaerts RM, Vaeyens R, Janssens M, Van Renterghem B, Matthys D, Craen R, et al. The relationship between peak height velocity and physical performance in youth soccer players. J Sports Sci. 2006;24(3):221-30. doi: 10.1080/02640410500189371.
12. Silva B, Clemente FM, Camões M, Bezerra P. Functional movement screen scores and physical performance among youth elite soccer players. Sports (Basel). 2017;5(1):16. doi: 10.3390/sports5010016.
13. Myer GD, Ford KR, Divine JG, Wall EJ, Kahanov L, Hewett TE. Longitudinal assessment of noncontact anterior cruciate ligament injury risk factors during maturation in a female athlete: a case report. J Athl Train. 2009;44(1):101-9. doi: 10.4085/1062-6050-44.1.101.
14. Portas MD, Parkin G, Roberts J, Batterham AM. Maturational effect on Functional Movement Screen™ score in adolescent

soccer players. J Sci Med Sport. 2016;19(10):854-8. doi: 10.1016/j.jsams.2015.12.001.
15. Mirwald RL, Baxter-Jones AD, Bailey DA, Beunen GP. An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc. 2002;34(4):689-94. doi: 10.1097/00005768-200204000-00020.
16. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N, et al. Enhancing a somatic maturity prediction model. Med Sci Sports Exerc. 2015;47(8):1755-64. doi: 10.1249/mss.0000000000000588.
17. Cornell DJ, Ebersole KT. INTRA-RATER test-retest reliability and response stability of the FUSIONETICS™ movement efficiency test. Int J Sports Phys Ther. 2018;13(4):618-32.
18. Bagherian S, Rahnama N, Wikstrom EA, Clark MA. Relationships between functional movement assessments and elements of sensorimotor function in collegiate athletes with chronic ankle instability. Sci J Rehabil Med. 2018;7(2):138-47. doi: 10.22037/jrm.2018.111034.1708.
19. Bagherian S, Rahnama N, Wikstrom EA, Clark MA, Rostami F. Characterizing lower extremity movement scores before and after fatigue in collegiate athletes with chronic ankle instability. Int J Athl Ther Train. 2018;23(1):27-32. doi: 10.1123/ijatt.2017-0029.
20. Bagherian S, Rahnama N, Wikstrom EA. Corrective exercises improve movement efficiency and sensorimotor function but not fatigue sensitivity in chronic ankle instability patients: a randomized controlled trial. Clin J Sport Med. 2019;29(3):193-202. doi: 10.1097/jsm.0000000000000511.
21. Wright AA, Stern B, Hegedus EJ, Tarara DT, Taylor JB, Dischiavi SL. Potential limitations of the functional movement screen: a clinical commentary. Br J Sports Med. 2016;50(13):770-1. doi: 10.1136/bjsports-2015-095796.
22. Yildiz S. Relationship between functional movement screen and athletic performance in children tennis players. Univers J Educ Res. 2018;6(8):1647-51.
23. Boguszewski D, Jakubowska K, Adamczyk JG, Białoszewski D. The assessment of movement patterns of children practicing karate using the functional movement screen test. J Combat Sports Martial Arts. 2015;6(1):21-6. doi: 10.5604/20815735.1174227.
24. Lloyd RS, Oliver JL, Radnor JM, Rhodes BC, Faigenbaum AD, Myer GD. Relationships between functional movement screen scores, maturation and physical performance in young soccer players. J Sports Sci. 2015;33(1):11-9. doi: 10.1080/02640414.2014.918642.
25. Malina R, Bouchard C, Bar-Or O. Timing and sequence of changes during adolescence. In: Growth, Maturation, and Physical Activity. Human Kinetics; 2004. p. 307-33.
26. Malina RM, Eisenmann JC, Cumming SP, Ribeiro B, Aroso J. Maturity-associated variation in the growth and functional capacities of youth football (soccer) players 13-15 years. Eur J Appl Physiol. 2004;91(5-6):555-62. doi: 10.1007/s00421-003-0995-z.
27. Tanner JM. Foetus into Man: Physical Growth from Conception to Maturity. Harvard University Press; 1990.
28. Avsiyevich V, Plakhuta G, Fyodorov A. The importance of biological age in the control system of training process of young men in powerlifting. Res J Pharm Biol Chem Sci. 2016;7(5):945-54. doi: 10.2139/ssrn.2990214.
29. Agresta C, Church C, Henley J, Duer T, O'Brien K. Single-leg squat performance in active adolescents aged 8-17 years. J Strength Cond Res. 2017;31(5):1187-91. doi: 10.1519/jsc.0000000000001617.
30. Krosshaug T, Steffen K, Kristianslund E, Nilstad A, Mok KM, Myklebust G, et al. The vertical drop jump is a poor screening test for ACL injuries in female elite soccer and handball players: a prospective cohort study of 710 athletes. Am J Sports Med. 2016;44(4):874-83. doi: 10.1177/0363546515625048.
31. Erwin HE, Castelli DM. National physical education standards: a summary of student performance and its correlates. Res Q Exerc Sport. 2008;79(4):495-505. doi: 10.1080/02701367.2008.10599516.
32. Lehance C, Binet J, Bury T, Croisier JL. Muscular strength, functional performances and injury risk in professional and junior elite soccer players. Scand J Med Sci Sports. 2009;19(2):243-51. doi: 10.1111/j.1600-0838.2008.00780.x.
33. van der Sluis A, Elferink-Gemser MT, Brink MS, Visscher C. Importance of peak height velocity timing in terms of injuries in talented soccer players. Int J Sports Med. 2015;36(4):327-32. doi: 10.1055/s-0034-1385879.
34. Rössler R, Donath L, Bizzini M, Faude O. A new injury prevention programme for children's football--FIFA 11+Kids--can improve motor performance: a cluster-randomised controlled trial. J Sports Sci. 2016;34(6):549-56. doi: 10.1080/02640414.2015.1099715.
35. Johnson DM, Williams S, Bradley B, Sayer S, Murray Fisher J, Cumming S. Growing pains: maturity associated variation in injury risk in academy football. Eur J Sport Sci. 2020;20(4):544-52. doi: 10.1080/17461391.2019.1633416.
36. Malina RM, Kozieł SM. Validation of maturity offset in a longitudinal sample of Polish boys. J Sports Sci. 2014;32(5):424-37. doi: 10.1080/02640414.2013.828850.
37. Malina RM, Rogol AD, Cumming SP, Coelho e Silva MJ, Figueiredo AJ. Biological maturation of youth athletes: assessment and implications. Br J Sports Med. 2015;49(13):852-9. doi: 10.1136/bjsports-2015-094623.
38. Arede J, Fernandes J, Moran J, Norris J, Leite N. Maturity timing and performance in a youth national basketball team: do early-maturing players dominate? Int J Sports Sci Coach. 2021;16(3):722-30. doi: 10.1177/1747954120980712.
39. Ramos SA, Massuça LM, Volossovitch A, Ferreira AP, Fragoso I. Morphological and fitness attributes of young male Portuguese basketball players: normative values according to chronological age and years from peak height velocity. Front Sports Act Living. 2021;3:629453. doi: 10.3389/fspor.2021.629453.