

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

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Abstract

The study aimed to examine the effect of biological age on the development of basic physical fitness attributes among under-15 football players. The comparative descriptive method was applied to a sample of 80 players from Sétif clubs, each with more than three years of training experience. Data analyzed using SPSS-27 and the independent samples *t*-test revealed that biological maturity significantly influences physical fitness levels, and that relying solely on chronological age does not reflect the actual developmental status of young football players.

Key words: physiological constraints; fundamental physical fitness attributes; biological age; under-15 age category.

المخلص

هدفت الدراسة إلى توضيح أثر العمر البيولوجي في تطور الصفات البدنية الأساسية لدى لاعبي كرة القدم أقل من 15 سنة، استخدم الباحث المنهج الوصفي المقارن على عينة مكونة من (80) لاعباً من أندية سطيف، يتمتعون بخبرة تدريبية تفوق ثلاث سنوات، أظهرت نتائج تحليل البيانات باستخدام برنامج (SPSS-27) واختبار "ت" لعينتين مستقلتين أن النضج البيولوجي يعد عاملاً مؤثراً في مستوى الصفات البدنية الأساسية، وأن الاعتماد على العمر الزمني فقط لا يعكس النمو الحقيقي للاعبين كرة القدم الناشئين.

الكلمات المفتاحية: القيود الفسيولوجية؛ الصفات البدنية الأساسية؛ العمر البيولوجي؛ الفئة العمرية أقل من 15 سنة.

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The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

1-Introduction:

Biological age represents a pivotal concept for understanding the human body's responses to sports training, particularly among young athletes who have not yet reached full maturation. During the period preceding the fifteenth year, the neuromuscular system does not develop uniformly across individuals; structural and functional growth rates vary according to the maturity of internal physiological processes (Malina et al., 2004, pp. 95–96).

Weineck (2010, p. 57) highlights that this stage constitutes a critical period for nervous system development, characterized by enhanced neural pathway efficiency and improved voluntary motor control. However, this neural advancement does not always coincide with muscle development, resulting in disparities in strength and speed among athletes of the same chronological age. Cometti (1998, p. 88) emphasizes that such differences reflect the influence of biological age on motor control and training responsiveness, indicating that chronological age alone is insufficient to explain variations in physical performance.

Physiological literature further suggests that applying training loads without consideration of an athlete's biological maturity can lead to excessive fatigue or delayed neuromuscular development, negatively affecting performance (Matveiev, 1981, p. 211). Reports from the FIFA Medical Centre (2015) confirm that exceeding the adaptive capacity of younger athletes without accounting for their maturation stage increases the risk of muscular injuries and disrupts neuromotor coordination.

Based on the above, this study aims to analyze statistical differences in fundamental physical attributes between two groups of athletes under 15 years of age who are similar in chronological age but differ in biological age, using the Maturity Offset index (Mirwald et al., 2002) to assess maturation levels. The expected outcomes are intended to demonstrate that the development of physical qualities such as speed, strength, and endurance is more closely associated with biological age than with chronological age.

General Research Problem:

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

- Are there statistically significant differences in fundamental physical attributes (speed, maximal strength, endurance, and neuromuscular coordination) among athletes under 15 years?

Specific Research Questions :

1. Are there statistically significant differences in motor speed between athletes with positive and negative biological age?
2. Do differences in biological age between groups lead to statistically significant variations in maximal strength?
3. Are there statistically significant differences in muscular and neural endurance among athletes differing in biological age?
4. Does variation in biological age (maturation) affect neuromuscular coordination despite participants having similar chronological age?

General Hypothesis:

- There are statistically significant differences in fundamental physical attributes (speed, maximal strength, endurance, and neuromuscular coordination) among athletes under 15 years.

Specific Hypotheses :

1. Statistically significant differences exist in motor speed between athletes with positive and negative biological age.
2. Statistically significant differences in maximal strength appear according to differences in biological age between the two groups.
3. Statistically significant differences exist in muscular and neural endurance among athletes with differing biological age.
4. Differences in biological age (maturation) are reflected in neuromuscular coordination, despite participants being similar in chronological age.

2- General objective of the study:

1. To determine the impact of biological age on the development of fundamental physical attributes in athletes under 15 years of age.

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

2. To compare two groups of athletes matched in chronological age but differing in biological age, in order to clarify the influence of maturation on physical performance indicators.
3. To analyze differences in speed, maximal strength, endurance, and neuromuscular coordination according to variations in biological maturity.
4. To provide practical recommendations for adapting training programs for young athletes in alignment with their biological maturity rather than solely their chronological age.

3-Significance of the Study:

The importance of this study stems from the need to reassess training foundations for young football players, as many programs rely exclusively on chronological age without accounting for differences in biological maturation. Such variation is a critical factor in explaining differences in physical performance and training responsiveness (Malina et al., 2004, p. 172).

Additionally, the study contributes to the scientific literature on the relationship between neuromuscular development and the effectiveness of early physical training (Philippaerts et al., 2006, p. 125), providing a practical model for classifying athletes according to biological maturity indicators (Mirwald et al., 2002, p. 709).

From an applied perspective, the expected findings will assist coaches in designing fairer and more efficient training programs that consider individual differences in maturation, thereby enhancing performance and reducing the risk of injury associated with overexertion or physiological mismatch.

4-Key Terms of the Study:

4-1-Physiological Constraints of Neuromuscular Development:

Conceptual Definition: Refers to the set of internal biological determinants related to the functioning of the nervous and muscular systems, influencing an individual's ability to control movement and generate force. This includes neural conduction efficiency, muscle contraction speed, and neuromuscular coordination (Weineck, 2010, p. 57; Bompà & Buzzichelli, 2019, p. 44).

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

Operational Definition: In this study, it encompasses physiological variables (neural transmission speed, reaction time, contraction efficiency, neuromuscular coordination) that determine the effectiveness of physical performance in athletes under 15 years according to biological age differences.

4-2-Basic Physical Qualities: Conceptual Definition: Fundamental motor abilities forming the basis of athletic performance, including speed, strength, endurance, and flexibility, developing according to genetic, physiological, and environmental factors (Hoffman, 2014, p. 12).

Operational Definition: In this study, basic physical qualities refer to measurable indicators such as motor speed, maximal strength, neuromuscular endurance, and motor coordination, assessed to examine the effect of biological age on their development.

4-3-Biological Age: Conceptual Definition: The actual level of body maturation resulting from hormonal and physiological changes in vital systems, considered more accurate than chronological age in estimating growth and physical maturity (Malina, Bouchard, & Bar-Or, 2004, p. 95).

Operational Definition: Biological age in this study refers to the degree of somatic and physiological maturity, determined through growth indicators (height, weight, bone age, hormonal characteristics), used to classify athletes into categories (positive maturity – negative maturity) despite similar chronological ages.

4-4-Athletes Under 15 Years Old: Conceptual Definition: This category represents early adolescence, characterized by accelerated neuromuscular and hormonal growth, making it a sensitive period for physiological adaptations to training (Rowland, 2005, p. 88).
Operational Definition: In this study, athletes under 15 years are male participants affiliated with local sports clubs, aged 13–15 years, undergoing regular training programs supervised by certified coaches.

5-Research Methodology:

The study employed a comparative descriptive design, deemed appropriate for examining a natural phenomenon characterized by differences in neuromuscular maturation between two independent groups of youth soccer players under 15 years old. This approach

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

allows for the observation and description of the phenomenon in its natural context, without researcher intervention, while enabling comparisons between biologically distinct groups (Malina & Bouchard, 1991, p. 212).

6-Population and Sample:

The target population comprised all under-15 soccer teams in the Sétif province of Algeria, a critical developmental stage in neuromuscular growth, coinciding with rapid hormonal and physiological changes associated with biological maturation (Malina, Bouchard, & Bar-Or, 2004, p. 103).

A purposive sample of 80 players was selected based on the following criteria: a minimum of three years of structured training experience at local clubs, absence of recent injuries, and no chronic conditions that could affect neuromuscular performance.

Participants were classified into two independent groups according to their biological maturity, calculated using the *Maturity Offset* equation proposed by Mirwald et al. (2002, p. 692):

$$\left(\frac{\text{Weight}}{\text{Height}} \right) 0.02292 + (\text{Sitting} \times \text{Age}) 0.007216 + (\text{Leg} \times \text{Age}) 0.001663 - (\text{Sitting} \times \text{Leg}) 0.0002708 + 9.236 - = MO$$

- **Biologically Mature Group:** 40 players who had surpassed peak height velocity ($\text{PHV} > 0.0$ years).
- **Biologically Less Mature Group:** 40 players who had not yet reached peak height velocity ($\text{PHV} \leq 0.0$ years).

This categorization was intended to examine the influence of biological maturation on differences in physical performance and neuromuscular capacities. The underlying premise is that hormonal changes associated with maturation affect muscle fiber development, neural conduction velocity, and motor control (Beunen & Malina, 2008, p. 45).

7-Preliminary Study :

Phase One:

The initial phase focused on assessing the procedural aspects of the study. This involved identifying potential obstacles that could hinder field implementation, verifying the suitability and accuracy of the

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

equipment used to measure neuromuscular variables, and training the research team on measurement protocols while standardizing the time required for each test (Thomas, Nelson, & Silverman, 2015, p. 131; ACSM, 2018, p. 47).

Phase

Two

The main assessments were conducted and subsequently repeated after a four-day interval to examine their validity and reliability. Test–retest reliability coefficients were calculated to ensure the precision of measurement instruments, which is critical in physiological research (Hopkins, 2000, p. 157; Malina, 2004, p. 122).

8-Methodological Justification for Classification:

The classification in this study was based on biological maturity, which is considered one of the most important determinants of performance differences among young athletes. Reaching the Peak Height Velocity (PHV) represents a physiological milestone associated with significant neuromuscular changes, including enhanced motor control and increased muscle fiber efficiency (Malina, 2004, p. 334). Accordingly, players were divided into two biological maturity groups using the maturity-offset calculated according to the equation proposed by Mirwald et al. (2002, p. 692):

- **Less mature group:** maturity-offset ≤ 0.0 years (pre-PHV).
- **More mature group:** maturity-offset > 0.0 years (post-PHV).

This division provides a direct physiological explanation for differences in neuromuscular activation and muscle responsiveness to training (Malina, 2004, p. 339). If group sizes were unequal, a median split could be applied to balance the sample while preserving the biological relevance of PHV classification.

9-Measurement Protocol for Classification:

Biological age was determined using the maturity-offset equation by Mirwald et al. (2002, p. 690), a field-based indicator estimating PHV based on precise chronological age, standing height, sitting height, and body mass. This measure is widely recognized for its ease of application and accuracy in assessing adolescent athletes compared to radiological methods (Malina et al., 2004, p. 102).

9-1-Physical Fitness Tests :

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

9-1-1-Reaction Tap Test (Motor Speed Test):

Objective: To assess neuromuscular reaction speed.

Equipment: Reaction tap device or specialized electronic application, chair, table.

Procedure: The athlete sits with the dominant hand placed on the device and is instructed to tap as quickly as possible in response to a visual signal for 10 seconds. Two familiarization trials are performed, and the best trial is recorded.

Recording: Total number of taps during 10 seconds using the dominant hand (Aurlien Broussal-Darval et Olivier Bolliet, 2012, p. 168)

9-1-2-Squat Test (Maximum Strength Test):

Objective: To measure maximal lower-body muscle strength, targeting the quadriceps and gluteal muscles.

Equipment: Barbell, measuring platform, technical assistant.

Procedure: After a standardized warm-up, the athlete performs a full squat (1RM) to determine the maximum weight that can be lifted for a single repetition using a gradual load-increment approach.

Recording: Maximum successfully lifted weight in kilograms (Aurlien Broussal-Darval et Olivier Bolliet, 2012, p. 90)

9-1-3-TOMBO Test (Muscular Endurance Test):

Objective: To evaluate the ability of muscles to perform continuous repetitions under moderate resistance.

Equipment: Exercise mat, stopwatch, field observer.

Procedure: The athlete performs sit-ups in a partial sitting position for one minute. Only correctly executed repetitions are counted.

Recording: Total number of correct repetitions within one minute (Aurlien Broussal-Darval et Olivier Bolliet, 2012, p. 104)

9-1-4-T-Test (Neuromuscular Coordination Test):

Objective: To assess agility and the ability to change directions quickly and accurately.

Equipment: Four cones, measuring tape, digital stopwatch.

Procedure: Cones are arranged in a T-shape (5 m between cones). The athlete starts at the base of the T, runs forward to the middle, moves laterally to the right and left cones, and returns backward to the starting point.

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

Recording: Total time in seconds; the best attempt is recorded (Aurlien Broussal-Darval et Olivier Bolliet, 2012, p. 140)

10- Scientific Basis of the Tests:

10-1-Test Reliability:

Reliability refers to the consistency of test results when repeated under identical conditions, i.e., the accuracy in measuring the intended phenomenon (Farhat, 2007, p. 143). As noted by Abdelhadi (1999, p. 66), a reliable test produces similar outcomes when administered multiple times to the same individuals under the same conditions.

In the current study, reliability was assessed using the **Test–Retest** method. The tests were applied to a pilot sample of 8 players from the research population and repeated after four days under the same conditions. Pearson's correlation coefficient (r) was used to measure the consistency between the two applications.

Table 1. Reliability and Self-Validity of Neuromuscular Tests in Soccer Players Under 15 Years

Test	Mean (Test)	SD	Mean (Retest)	SD	Pearson r (Reliability)	Self-Validity (√r)
Reaction Tap Test	48.2 taps / 10 s	3.6	48.7 taps / 10 s	3.4	0.82	0.91
Squat Test	44.8 kg	2.6	45.2 kg	2.5	0.79	0.89
Sit-ups 1 min Test	42.5 reps	2.8 5	42.7 reps	2.6 5	0.76	0.87
T-Test	10.25 s	0.6 1	10.31 s	0.5 8	0.80	0.89

The values indicate that reliability coefficients ranged from 0.76 to 0.82, and self-validity coefficients ranged from 0.87 to 0.91, reflecting high reliability and stability of the tests. These findings are consistent with standards suggested by Hopkins (2000) and Morrow et al. (2011) for field-based sports measurements.

10-2-Test Validity:

Although the tests used in this study had been previously validated, their validity was confirmed in two ways:

227

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years
Smara Mohamed

10-2-1-Content Validity: The researcher presented the test content to a panel of seven experts in exercise physiology and kinesiology, all of whom agreed that the tests were appropriate for the sample and research objectives, incorporating their recommendations.

10-2-2-Self-Validity: Calculated as the square root of the reliability coefficient ($\sqrt{r}$), with all values exceeding 0.85, indicating high measurement accuracy and performance stability.

10-3-Test Objectivity:

Objectivity is achieved when a test yields the same results regardless of the scorer (Saber, 2003, p. 164). To ensure objectivity, the researcher employed tests with simple, clear instructions, provided practical demonstrations before official administration, and used precise digital timing and measuring instruments, minimizing observer bias and enhancing result accuracy (Baumgartner & Jackson, 1999).

11-Normality Test (Kolmogorov–Smirnov):

Table 2. Normality Test for the Biologically Mature Group (n = 40)

Variable	Mean	SD	Skewn ess	Kurtosi s	Kolmogor ov– Smirnov	Sig (p)	Notes
Reaction Tap Test (taps / 10 s)	64.30	4.12	-0.21	-0.48	0.093	0.20 0	Normal distribution
Maximum Strength (kg)	46.75	6.28	0.19	-0.67	0.101	0.18 4	Normal distribution
Muscular Endurance (reps / min)	41.60	3.97	-0.11	-0.31	0.089	0.21 3	Normal distribution
Neuromuscul ar Coordination (s)	10.72	0.61	0.27	-0.22	0.097	0.19 2	Normal distribution

The Kolmogorov–Smirnov test results for the biologically mature group show that the significance values (Sig) ranged from 0.184 to 0.213, all exceeding 0.05. Skewness values ranged from -0.21 to 0.27, and kurtosis values from -0.67 to -0.22, indicating that the data are approximately normally distributed. Therefore, reaction speed (64.30

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years
Smara Mohamed

± 4.12), maximum strength (46.75 ± 6.28), muscular endurance (41.60 ± 3.97), and neuromuscular coordination (10.72 ± 0.61) all meet the assumptions for parametric statistical analyses.

Table 3. Normality Test for the Biologically Immature Group (n = 40)

Variable	Mean	SD	Skewness	Kurtosis	Kolmogorov-Smirnov	Sig (p)	Notes
Reaction Tap Test (taps / 10 s)	58.95	4.43	-0.15	-0.37	0.086	0.228	Normal distribution
Maximum Strength (kg)	42.20	5.71	0.23	-0.54	0.094	0.205	Normal distribution
Muscular Endurance (reps / min)	38.90	3.65	-0.19	-0.28	0.081	0.241	Normal distribution
Neuromuscular Coordination (s)	11.08	0.73	0.25	-0.34	0.099	0.187	Normal distribution

The results for the biologically immature group show significance values ranging from 0.187 to 0.241, all greater than 0.05, confirming no significant deviation from normality. Skewness values varied between -0.19 and 0.25, and kurtosis values between -0.54 and -0.28, reflecting symmetry around the mean without extreme deviations. Accordingly, all variables—reaction speed (58.95 ± 4.43), maximum strength (42.20 ± 5.71), muscular endurance (38.90 ± 3.65), and neuromuscular coordination (11.08 ± 0.73)—follow a normal distribution, justifying the use of the **Independent Samples T-Test** in subsequent analyses.

12-Statistical Tools Used :

- Mean and standard deviation (SD)
- Skewness and kurtosis
- Shapiro–Wilk Test

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

- Pearson’s correlation coefficient (r)
- Square root of the reliability coefficient ($\sqrt{r}$) for self-validity
- Independent Samples T-Test
- Effect size (Cohen’s d)

13-Results and Discussion:

Table 4. Results of the Independent Samples T-Test for Reaction Speed (**Reaction Tap Test**)

Group	Mean ± SD	t	Sig (p)	Significance Level α	Cohen’s d	Difference Significance
Biologically Mature	64.30 ± 4.12	5.64	0.000	0.05	1.23	Statistically significant
Biologically Immature	58.95 ± 4.43					

Figure 1. Graphical representation of the mean values for the biologically mature and immature groups in the **Reaction Tap Test**.



The results show a clear superiority of the biologically mature group in reaction speed, with a mean number of taps in 10 seconds of 64.30 ± 4.12 compared to 58.95 ± 4.43 for the immature group. The significance value ($\text{Sig} = 0.000$) is below 0.05, indicating a statistically significant difference between the two groups. This finding suggests that neuromuscular maturation contributes to faster responses to visual stimuli due to more efficient integration between the central nervous system and muscles, resulting in precise and repeated movements (Weineck, 2019, p. 211). The large effect

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

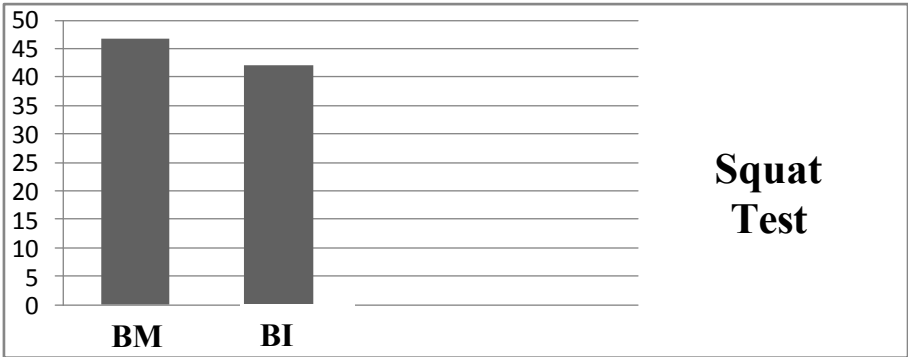
Smara Mohamed

size (Cohen’s $d = 1.23$) highlights a practically strong impact, emphasizing the importance of considering biological maturity in selecting and training players under 15 years of age.

Table 5. Results of the Independent Samples T-Test for Maximum Strength (**Squat Test**)

Group	Mean ± SD	t	Sig (p)	Significance Level α	Cohen’ s d	Difference Significance
Biologically Mature	46.75 ± 6.28	3.25	0.002	0.05	0.73	Statistically significant
Biologically Immature	42.20 ± 5.71					

Figure 2. Graphical representation of the mean values for the biologically mature and immature groups in the **Squat Test**.



The maximum strength test also revealed that biologically mature players performed better, with an average of 46.75 ± 6.28 kg compared to 42.20 ± 5.71 kg for the immature group. The statistical difference was significant ($p = 0.002 < 0.05$), indicating that biological maturation directly influences maximum muscular strength.

This can be explained by increased muscle fiber mass and enhanced neuromuscular coordination with advancing biological maturity, allowing the recruitment of a higher number of motor units during exertion (Bompa & Haff, 2019, p. 156). The effect size ($d = 0.73$) demonstrates that the difference is not only statistically significant but also practically meaningful, supporting the rationale for classifying players by maturity rather than chronological age alone.

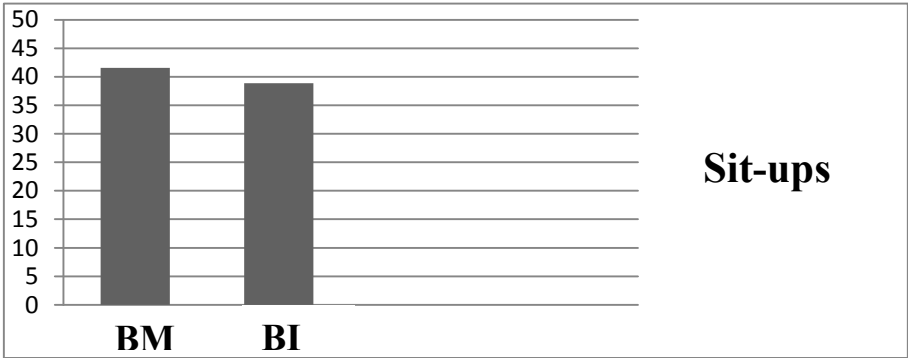
The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

Table 6. Independent Samples T-Test Results for Muscular Endurance (Sit-ups Test)

Group	Mean ± SD	t	Sig. (p)	Significance Level α	Cohen's d	Significance Differences
Biologically Mature	41.60 ± 3.97	2.99	0.004	0.05	0.67	Statistically significant
Biologically Immature	38.90 ± 3.65					

Figure 3. Graphical representation of the mean values for the biologically mature and immature groups in the **Sit-ups Test**.



The results reveal significant differences in muscular endurance between the two groups, with biologically mature players performing a higher number of repetitions within one minute. The p-value ($p = 0.004$) is below 0.05, indicating statistical significance. This outcome can be attributed to the enhanced metabolic efficiency of muscle tissue in mature individuals, characterized by an increased number of mitochondria and faster clearance of fatigue by-products, thereby sustaining performance for longer periods (Kenney et al., 2021, p. 201). The effect size (Cohen's $d = 0.67$) is moderate, suggesting the differences have practical relevance in talent identification and training programs.

Table 7. Independent Samples T-Test Results for Neuromuscular Coordination (T-Test)

Group	Mean ± SD	t	Sig. (p)	Significance Level α	Cohen's d	Significance Differences
Biologically Mature	10.72 ± 0.61	-2.37	0.020	0.05	0.53	Statistically significant

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

Biologically Immature	11.08 ± 0.73					
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Figure 4. Graphical representation of the mean values for the biologically mature and immature groups in the **T-Test**.



The T-Test results indicate significant differences ($p = 0.020 < 0.05$), with the biologically mature group exhibiting lower completion times, reflecting superior coordination across lateral, forward, and backward movements. This advantage is likely due to the development of the central nervous system and faster neural signal transmission, which improves spatial-temporal accuracy in movement execution (Baechle & Earle, 2008, p. 243). The effect size (Cohen’s $d = 0.53$) is moderate, confirming that the observed differences are not random but reflect genuine functional advancement in motor coordination among mature participants.

13-1-Discussion of Results in Light of the Hypotheses:

13-1-1-Partial Hypothesis 1:

Hypothesis: There are statistically significant differences in motor speed between athletes with advanced and delayed biological age.

The results of the Reaction Tap Test revealed statistically significant differences ($p \leq 0.05$) in favor of the biologically mature group, with a mean of 64.30 ± 4.12 taps compared to 58.95 ± 4.43 for the less mature group, indicating a clear superiority in motor response speed. This outcome can be explained through neuromuscular maturation, as complete myelination of the nervous system in biologically mature individuals enhances neural transmission speed and response time (Granacher et al., 2018). These findings are consistent with Philippaerts et al. (2006), who reported improved performance in

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

rapid skills following peak height velocity (PHV). Therefore, the first hypothesis is accepted, suggesting that biological maturation contributes to improved motor responses via enhanced central and peripheral neural control.

13-1-2-Partial Hypothesis 2:

Hypothesis: There are statistically significant differences in maximal strength according to biological age.

The Squat Test results showed significant differences in favor of the biologically mature group, with a mean maximal strength of 46.75 ± 6.28 kg compared to 42.20 ± 5.71 kg for the less mature group. These findings indicate that hormonal maturation, particularly increases in testosterone and growth factors (GH and IGF-1), plays a critical role in muscle mass development and maximal strength (Malina, Bouchard & Bar-Or, 2004). Lloyd et al. (2014) further emphasized that biological development directly affects the response to resistance training, even in the absence of differences in training volume or type. Thus, the second hypothesis is supported, confirming the positive influence of biological maturation on maximal strength through hormonal and morphological changes.

13-1-3-Partial Hypothesis 3:

Hypothesis: There are statistically significant differences in muscular and neuromuscular endurance between athletes of different biological ages.

The Sit-ups Test demonstrated significant differences ($p \leq 0.05$) favoring the biologically mature group, with a mean of 41.60 ± 3.97 repetitions versus 38.90 ± 3.65 repetitions for the less mature group. This can be attributed to improved cardiorespiratory efficiency and muscular endurance associated with biological maturation, as increases in heart size, lung capacity, and metabolic system maturity enhance muscles' resistance to fatigue (Malina et al., 2004). Chen et al. (2023) supported this observation, reporting that endurance training responses are more effective following structural and hormonal maturation. Accordingly, the third hypothesis is accepted, highlighting the integration of cardiovascular and central nervous system maturation in enhancing muscular endurance.

13-1-4-Partial Hypothesis 4:

Hypothesis: Differences in biological age (maturation) affect neuromuscular coordination despite similar chronological ages.

T-Test results showed that the biologically mature group performed better, with a mean time of 10.72 ± 0.61 seconds compared to 11.08 ± 0.73 seconds for the less mature group ($p \leq 0.05$). This reflects the advancement of motor integration within the central nervous system and muscular structures, where maturation of fine motor pathways improves timing and movement sequencing (Granacher et al., 2018). These findings align with Bizzini et al. (2015), who demonstrated enhanced motor coordination in children participating in the "FIFA 11+ Kids" program as biological maturity increased. Therefore, the fourth hypothesis is accepted, confirming that neuromotor maturation is a key determinant of movement coordination in this age group.

13-1-5-General Hypothesis:

There are statistically significant differences in fundamental physical attributes (speed, maximal strength, endurance, and neuromuscular coordination) among athletes under 15 years.

The results from all four tests consistently showed statistically significant differences favoring the biologically mature group. This confirms that biological age is a critical determinant of physical performance in youth athletes, independent of chronological age. These outcomes are in agreement with Mirwald et al. (2002) and Philippaerts et al. (2006), who reported that maturation status (pre- or post-PHV) is closely linked to diverse physical capacities. Additionally, consensus findings by Lloyd et al. (2014) and Granacher et al. (2018) emphasize that strength, coordination, and endurance development should be designed according to maturation level rather than solely chronological age. Consequently, the general hypothesis is accepted, underscoring the importance of adopting biologically based classification in youth sports to ensure equitable evaluation and effective training program planning.

14-Conclusions:

Based on the analysis of the results and their discussion in light of the study hypotheses and previous research, the following conclusions can be drawn:

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

1. Biological maturation is a significant determinant of fundamental physical performance in players under 15 years of age. Biologically mature individuals exhibited higher levels of motor speed, maximal strength, muscular endurance, and neuromuscular coordination compared to their less mature peers.
2. Relying solely on chronological age to categorize youth players does not accurately reflect their true developmental status, as athletes of similar age may differ considerably in body composition and functional capacities.
3. The superiority of the biologically mature group highlights the positive impact of hormonal changes and increased muscle mass on physical performance, in line with findings by Malina et al. (2004) and Philippaerts et al. (2006) regarding the influence of the peak height velocity (PHV) phase on motor competence.

Reference:

1. Abdelhadi, N, 1999, Educational Measurement and Evaluation. Dar Wael for Printing and Publishing, 1st ed., Jordan.
2. Alcock, R., et al. (2024). Youth and Adolescent Athlete Musculoskeletal Health: Dietary and Nutritional Strategies to Optimise Injury Prevention and Support Recovery. Journal of Functional Morphology and Kinesiology, 9(4), 221.
3. Aurlien Broussal-Darval et Olivier Bolliet, (2012). les test de terrain, 4éditions, lyon, France.
4. Baumgartner, T. A., & Jackson, A. S. (1999). Measurement for evaluation in physical education and exercise science. WCB/McGraw-Hill.
5. Beunen, G., & Malina, R. M. (2008). Growth and biologic maturation: Relevance to athletic performance. In Hebestreit, H., & Bar-Or, O. (Eds.), The Young Athlete. Blackwell Publishing. <https://doi.org/10.1002/9780470696255.ch1>
6. Bizzini, M., et al. (2015). The FIFA 11+ program and FIFA 11+ Kids resources. FIFA Medical Network / British Journal of Sports Medicine resources. <https://www.fifamedicalnetwork.com/>

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

7. Bompa, T. O., & Buzzichelli, C. (2019). *Periodization: Theory and Methodology of Training* (6th ed.). Human Kinetics. <https://us.humankinetics.com>
8. Brenner, J. S., et al. (2024). Overuse Injuries, Overtraining, and Burnout in Young Athletes. *Pediatrics*, 153(2), e2023065129. <https://doi.org/10.1542/peds.2023-065129>
9. Chen, L., et al. (2023). Maximizing plyometric training for adolescents: a meta-analysis of ground contact frequency and overall intervention time on jumping ability. *Scientific Reports*, 13, 21222. <https://doi.org/10.1038/s41598-023-48274-3>
10. Cometti, G. (1998). *Entraînement et musculation: Bases scientifiques et applications pratiques* (3e éd.). Vigot.
11. El-Sayed, F. L, 2007, *Measurement and Testing in Physical Education*, Al-Kitab Center, Cairo.
12. Faigenbaum, A. D., Myer, G. D., et al. (2009). Youth resistance training: position statement. National Strength and Conditioning Association. [NSCA resource].
13. Fédération Internationale de Football Association [FIFA] Medical Centre. (2015). FIFA 11+ and youth injury prevention guidelines. <https://www.fifamedicalnetwork.com/>
14. Granacher, U., Puta, C., Gabriel, H. H. W., Behm, D. G., & Arampatzis, A. (2018). Neuromuscular training and adaptations in youth athletes. *Frontiers in Physiology*, 9, 1264. <https://www.frontiersin.org/articles/10.3389/fphys.2018.01264/full>
15. Hoffman, J. R. (2014). *Physiological aspects of sport training and performance* (2nd ed.). Human Kinetics. <https://us.humankinetics.com/products/physiological-aspects-of-sport-training-and-performance-2nd-edition>
16. Lloyd, R. S., (2014). Position Statement on Youth Resistance Training: The 2014 International Consensus. *British Journal of Sports Medicine*, 48(7), 498–505. <https://doi.org/10.1136/bjsports-2013-092952>
17. Malina, R. M., et al. (2004). *Growth, Maturation, and Physical Activity* (2nd ed.). Human Kinetics. <https://doi.org/10.5040/9781492596364>

The Impact of Neuromuscular Growth Constraints on Physical Training in Athletes Under 15 Years

Smara Mohamed

18. Matveiev, L. P. (1981). Fundamentals of sports training. Progress Publishers.
19. Mirwald, R. L., et al. (2002). An assessment of maturity from anthropometric measurements. *Medicine & Science in Sports & Exercise*, 34(4), 689–694. <https://doi.org/10.1097/00005768-200204000-00020>
20. Morrow, J. R., et al. (2011). Measurement and evaluation in human performance (4th ed.). Champaign, IL: Human Kinetics.
21. Philippaerts, R. M., et al. (2006). The relationship between peak height velocity and physical performance in youth soccer players. *Journal of Sports Sciences*, 24(3), 221–230. <https://doi.org/10.1080/02640410500189371>
22. Rowland, T. W. (2005). Children's exercise physiology (2nd ed.). Human Kinetics. <https://us.humankinetics.com/products/childrens-exercise-physiology-2nd-edition>
23. Saber, F. A., & Khafaga, M. A, 2003, Fundamentals and Principles of Scientific Research. Al-Ishaa Technical Press and Library, Alexandria.
24. Weineck, J. (2010). Manuel d'entraînement sportif (5e éd.). Vigot. <https://vigot.com/produit/manuel-dentrainement-sportif>