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The level of body posture, the flexibility of backbone and flat feet in competition fitness in 8-11year old girls

ALEXANDRA VEIS, JANKA KANÁSOVÁ, NORA HALMOVÁ

Abstract
Introduction. **Such sports as fitness have high demands on the motor system, mainly on the foot arch. Repeated movements can expose the ankle joint and the sole of children practicing fitness sports to high loading.** Aim of Study. **The aim of this study was to determine the incidence of incorrect body posture, flexibility and flatfoot in children attending competition fitness classes.** Material and Methods. **The study population was composed of 18 children aged 8.9 to 10.3 years of age. Body posture was assessed using the eye-viewing method according to Klein and Thomas. Backbone flexibility was measured using tests of Schober´s and Stibor´s symptoms, right and left backbone lateral flexibility, Thomayer´s symptom, Otto´s inclination and the reclination symptom. Podoscopy was used to assess flatfoot degrees. All indicators were evaluated individually and statistical significance of the relationship between individual dimensions of body posture and flat feet were assessed using the chi-square (χ2) test.** Results. **The highest proportion of incorrect body posture in all tested children was recorded in the dimension of hips and shoulders (78%), backbone curvature (61%) and shoulderblades (55.6%). Flat feet were diagnosed according to Kapandji in 27.8% and 11.2% cases according to Srdečný. When investigating the relationship of flat feet in the test of Kapandji and Srdečný to the dimension of body posture statistical significance was recorded between flat feet and the dimension of hips and shoulders and backbone curvature. In the test of Srdečný a significant relationship was observed between flat feet and the dimensions of head, shoulderblade and abdomen.** Conclusions. **This study focused on the verification of the impact of the training process in fitness sports practiced by children on their body posture and flatfoot incidence. We recommend observing children for flatfoot symptoms, which can negatively influence the postural function in young athletes.**

KEYWORDS: body posture, flatfoot, competitive fitness, spine flexibility.

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Introduction

Nowadays, motor system disorders are one of the most frequent problems in children practicing sports. Reasons for the development of motor system malfunctions need to be searched for already in childhood when the child is exposed to inadequate loads. Muscular imbalance then causes wrong body posture. The functional disorder of the motor system is manifested by changes in body shape. These changes can be eliminated by determined effort, in contrast to real deformities or orthopedic malfunctions [12].

An erect posture is characterized in humans as the particular manner of the postural stereotype of an individual [13]. Postural stereotypes are formed since the childhood based on optimal and adequate stimuli. The term stability is closely connected with the term posture. In the human motor system it is understood as the state, when least loaded joint structures, and the muscles work in closest cooperation and the motion is performed most efficiently [24].

Stabilization (or fixation of the backbone during all movements) is ensured by the coordination of the muscles in the deep stabilization backbone system and is considered to be a prerequisite of the axial skeleton, providing protection from overloading [19]. Engagement of muscles into the stabilization process is automatic. There are several muscles that participate in the stabilization of the backbone. As a result of muscular interconnection, it is the whole muscular chain [14]. Postural balance is the ability to hold the body in a balanced position and to regain it again after a shift of body segments. This elementary motor skill is learned in childhood and represents the fundament for everyday routine tasks and sports activities [3, 22].

Researches in various countries showed posture disorders already in 29% of children and adolescents [4, 21, 27]. Moreover, the posture disorder is identified by visible changes in the posture, for example hyperlordosis, an increased frontal pelvic inclination or an anterior position of the head [17]. An incorrect posture is often connected with flat feet. The human foot is specialized for the performance of two different functions – static and dynamic. These aims are fulfilled by the series of bones forming various arches. The arches serve to dissipate forces applied to the plantar aspect of the foot. Changes in the height of the arch are related with the contraction or relaxation of tibial muscles [6]. Flatfoot (pes planus) is a relatively common phenomenon. For a majority of athletes flat feet do not cause any problems and have no impact on performance in sports. However, in certain sports disciplines flat feet can cause stiffness, inelasticity and pain. Baseball is the type of sport, which requires a long-lasting standing position and fast active movement. It is the sport, where flat feet can cause pain [29]. Some studies investigated posture and flatfoot in athletes. For example, Sharma and Upadhyaya studied the effect of flat feet on the running ability of track-and-fielders. In their study no difference was found in the degree of foot flatness in various athletes of different running (long or short distance) sports [25]. Fitness sports as competitive events for children were introduced in 2002. Children's fitness focuses on acrobatics, flexibility and power exercises, which ensure overall development of the child. The aim of the study was to determine the type of body posture, backbone flexibility and the incidence of flatfoot in children practicing competitive fitness sports.

Material and Methods

The analyzed sample was formed by 18 females (decimal age of 8.9 to 10.3 years), who are a part of the GymGol Nitra children's fitness club. Homogeneity of the sample population was reached by the single sex and age of the girls, as well as their identical performance level. The training units took place four times a week and lasted 90 minutes. All the girls performed them with the same strain in the same training unit.

All probands were placed in the first five places in the competitions in Slovakia. All probands have been practicing fitness sports since four years of age. To test the correct posture the standardized test of backbone curvature was applied using the plumb [5], the method by Klein and Thomas as modified by Mayer [20]. A total of six dimensions (head, thorax, backbone curvature, hips and shoulder lines, scapula and abdomen), were assessed visually. The examiners were two independent physiotherapists. Based on the assessment of the dimensions by marks from 1 through 4, where mark 4 is the worst, we assigned the girls to one of the four qualitative degrees: 1st degree – perfect posture, 2nd degree – good (almost perfect) posture, 3rd degree – wrong posture, and 4th degree – very bad posture.

Joint flexibility of the backbone was evaluated by means of five tests: the Schober test (Sch) – lumbar spine flexibility; the Stibor test (St) – flexibility of lumbar and thoracic segments; right and left backbone flexibility – lateral flexibility; the Thomayer test (Tho) – overall spine flexibility, and Otto inclination and reclination tests – flexibility of thoracic spine (Ot) [5].

Schober test (Sch)

From the 5th stem vertebra, mark upwards on the spine and mark the place.

Norm: when performing the maximum forward bend, this distance should be extended by 4-6 cm.

Stibor test (St)

While standing, we measure the distance from the projection of the 7th cervical vertebra to the 5th lumbar vertebra (C7–L5).

Norm: when forward, this distance is extended by 7.5--10 cm.

Otto inclination and reclination tests (Ot)

While standing, we mark the 1st thoracic vertebra on the spine (Th1) and apply 30 cm downwards and mark.

Norm: the distance is extended by 2-3 cm when bending forward and the distance is shortened by 2.5-3 cm when performing the inclination bend. The sum of deviations should be 6 cm.

Thomayer test (Tho)

In the standing position, a deep forward bend with reach is performed. The initial position is standing on a bench or elevated mat.

Norm: the hands touch the pad with their fingers.

Lateral flexion test
The depth of inclination to the right and left is measured after performing a maximum inclination of the torso. Physiological norm is 20-22 cm.
Reduced flexibility: if the elongation is less than the specified norm. Increased flexibility: if the elongation is greater than the specified norm.

LED Podoscope (02990) was used to test flatfoot signs.

The degree of flatfoot according to Kapandji
Healthy feet – standard; the 1st degree of flatfoot – slightly flat foot; the 2nd degree of flatfoot – markedy flat feet; the 3rd degree of flatfoot – the sole is markedly lowered, also when not loaded (Figure 1).

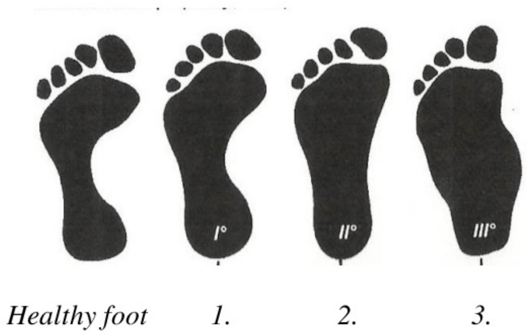

Figure 1. Visual scale according to Kapandji [11]

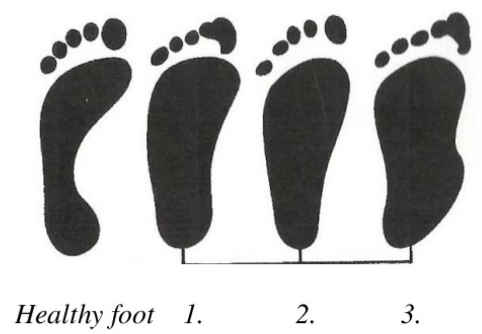

Figure 2. Visual scale according to Srdečný et al. [26]

The degree of flatfoot according to Srdečný et al.
Healthy feet standard, the sole is correct; the 1st degree of flatfoot – a more marked drop of the sole; 2nd degree of flatfoot – visually it is similar as in the 1st degree; the 3rd degree of flatfoot – the sole is markedly lowered, also when noy loaded (Figure 2).
When processing the data, arithmetic means, percentage and frequency analyses were used. In order to express the relationship between posture and the incidence of flatfoot the chi-square (χ^2) test was applied at the 1%, 5% and 10% level of statistical significance.

Results
When assessing posture in children attending fitness training, perfect posture was recorded in the dimension of the head (56% probands), good posture in 44%, while wrong posture and very bad head posture was not recorded. In the dimension of the thorax 89% of probands showed perfect posture and 11% good posture. Similarly as in the head posture, no cases of wrong and very bad posture were observed. In the backbone dimension 39% probands showed perfect posture, 50% good posture, 11% wrong posture, while no probands showed a very bad curvature of the backbone. In the dimension of the hips and shoulders 22% of probands showed perfect posture, while 78% good and wrong posture. No probands showed a very bad position of hips and shoulders. In the shoulder blade dimension 44% probands showed perfect posture, 39% good posture, 11% wrong posture, whereas one girl showed very bad posture, with protruding shoulder blades. In the abdomen dimension 56% of probands showed perfect posture, 39% good posture, one girl had the wrong posture, while no probands showed very bad posture (Table 1).
When assessing the overall posture we diagnosed one girl with perfect posture, 67% with good posture, 22% with the wrong posture and in one girl we recorded very bad posture.
The dimensions of the hips and shoulders with 78%, backbone curvature with 61% and shoulder blades with

Table 1. Qualitative degrees of posture

Degree/ dimensions	Head [%]	Thorax [%]	Backbone [%]	Hips and shoulders [%]	Shoulder blades [%]	Abdomen [%]
1st grade	56	89	39	22	44	56
2nd grade	44	11	50	78	39	39
3rd grade	0	0	11	0	11	5
4th grade	0	0	0	0	6	0

56% showed the percentages of probands with wrong body posture.
When comparing our results for evaluation of backbone curvature by means of the plumb line examination with the recommended values, we measured on average 2.1 cm in the case of cervical lordosis, while the recommended minimum is 2 cm and the maximal one is 2.5 cm. In the case of waist lordosis our value was 3.3 cm, while the recommended minimum is 3 cm and the recommended maximum is 3.5 cm. Joint flexibility of individual segments of the backbone was measured using 5 tests. In the case of Schober's test the probands reached 4.2 cm, which we evaluate as the norm according to the above-mentioned methodology. During the Stibor test we recorded a value of 8.4 cm, which we consider to be a norm.
In the case of lateral (right and left) flexibility of the backbone the recommended minimum and maximum for both right and left sides were 20-25 cm. The probands showed the values of 21 cm in the case of lateral flexibility to the right and 19.9 cm to the left. The standard value for Thomayer's test is that the fingertips should touch the ground, which was exceeded by our probands by 19.2 cm.
When comparing our probands' result of 3.8 cm in Otto's inclination symptom test with the maximum value of 2.5 cm and the minimum value of 2 cm, we can see that probands exceeded these values. In the case of Otto's reclination symptom test the recommended maximum value was 3 cm and the minimum value of 2.5 cm, while our probands recorded 2.8 cm.
The backbone flexibility indicators observed in our study were positive. The fitness sports probands in all tests reached the recommended standards of backbone flexibility with the exception of Otto's inclination symptom test, where we measured the value of 3.8 cm, while the recommended minimum is 2 and the maximum is 3 cm. Our probands exceeded the recommended maximum value by 0.8 cm (Table 2).
Out of the total number of probands, according to Kapandji [11] 94% of probands showed a healthy right leg and 72% probands a healthy left leg. The first degree of flatfoot in the right foot was diagnosed in one girl, while the first degree of flatfoot in the left leg was not diagnosed in any of the probands. No probands were diagnose with the second degree of flatfoot in the right foot and the left foot. The third degree was not diagnosed in any of the probands, whereas the third degree of flatfoot in the left foot was diagnosed in one girl. According to Srdečný et al. [26], the healthy left foot was diagnosed in all probands and the healthy right foot in 89% of probands. The first degree of flatfoot in the left foot was found in one girl, while the second degree of flatfoot in the left foot was not found in any of the probands. The third degree of flatfoot in the left foot was diagnosed in one girl.
When assessing the overall flatfoot incidence according to Kapandji healthy feet were diagnosed in 72% of probands. The first degree of flatfoot was diagnosed in 22% of probands, the second degree of flatfoot was not recorded in any of the probands, whereas the third degree was diagnosed in one of the probands. According to Srdečný et al., healthy feet were diagnosed in 89% of probands, while in one girl the first degree of flatfoot was observed. The second degree of flatfoot was not diagnosed at all, while the third degree was found in one girl.
When determining the relationship between flatfoot according to Kapandji and the types of body posture according to Klein and Thomas [20], we found a 10% statistical significance between flat feet and the dimension of the backbone, and 5% significance for the correlation between flat feet and the hips and shoulders dimension. In the case of other dimensions of posture no significance was found in their relationship to flat feet according to Kapandji. When determining the relationship of flatfoot according to Srdečný et al. with the dimensions of posture according to Klein

Table 2. Posture and backbone flexibility

Sample/test	Cervical lordosis (cm)	Waist lordosis (cm)	Schober's symptom (cm)	Stibor's symptom (cm)	Thomayer's test (cm)
SF	2.1 ± 0.63	3.3 ± 0.71	4.2 ± 1.12	8.4 ± 1.8	19.2 ± 6.29
Rmin	2	3	4.1	7.5	
Rmax	2.5	3.5	6	10	
Sample/ test	lateral backbone flexibility (right)	lateral backbone flexibility (left)	Otto´s inclination symptom	Otto´s reclination symptom	
SF	21 ± 2.4	19.9 ± 2.58	3.8 ± 1.67	2.8 ± 0.86	
Rmin	20	20	2	2.5	
Rmax	25	25	3	3	

Note: SF – the sample of fitness probands; Rmin – recommended minimum value; Rmax – recommended maximum value and Thomas, a statistically significant relationship was found at $p < 0.05$ between the sole and the dimensions of the head, shoulder blades and the abdomen. Statistical significance at $p < 0.01$ was confirmed between the sole and the dimensions of of the backbone and hips and shoulders (Table 3).

Table 3. Relationship of flatfoot according to Kapandji [11] and Srdečný et al. [26] with dimensions of posture

	Kapandji		Srdečný	
Dimensions	p-value	chí	p-value	chí
Head	0.4360	2.725	0.0497*	7.829
Thorax	0.7719	1.977	0.7213	1.333
Backbone	0.0813(*)	6.723	0.0048**	12.922
Hips and shoulders	0.0101*	11.32	0.0002**	19.467
Shoulder blades	0.2605	4.009	0.0271*	9.167
Abdomen	0.3605	3.209	0.0484*	7.885

* $p < 0.05$; ** $p < 0.01$; (*) $p < 0.10$

Discussion

Based on the fulfilled aims of the study we are presenting the part of the results, being the subject of further research. The presented results may not be generalized. It is necessary to understand them as partial ones with regard to further research. Our results are in line with the previous conclusions of the works [8, 9], where wrong posture was found in 100% of children aged 11 years attending general schools. The dimensions of hips and shoulders followed by backbone curvature and shoulder blades were the ones observed with the highest incidence of wrong posture in all probands. These results correspond with the findings in the school non-sporting population [9, 15]. Our findings of the relationship between flatfoot and posture correspond with the findings by Kanásová, who assumed that flat feet can to a high degree influence also the wrong body posture [10].

In our reference sample good posture was diagnosed in a majority of probands (67%), which according to the method of evaluation is considered to be a slight deviation from the standard. Healthy feet (assessed according to the quality of the sole) were recorded according to both methods in 72 up to 89% of probands. The sole represents one of the most important proprioceptive areas of the human body. It is not by chance that it is closely connected with postural functions. In terms of afferentation mainly the receptors in the area of the sole, hips and the neck play a crucial role in the erect body posture [7]. If the information from various receptors differs, they become the source of motor insecurities [28]. According to several authors [2], improper functional loading of the leg has a highly negative impact on overloading and the incidence of chronic changes not only in the area of the ankle joint and leg, but also in more proximal segments of the body within the whole kinematic chain. Many studies describe the connection between the sole, the deep stabilization system and posture [16, 18]. Both high and low arched feet have been reported to be factors making the foot more prone to injury during physical activities [23].

In our study these interconnections between the sole and posture were found in individual dimensions of posture. The activity of the deep stabilization system was not observed. When observing the impact of an intervention program on backbone flexibility in 136 female pupils of 4th grade in secondary schools (without any connection with flatfoot) it was found that the backbone, in terms of the overall dynamic function, after a 3-month aimed motor program with compensation focus in the sagittal and lateral planes became more dynamic and flexible. These results were supported by the statistically significant results ($p < 0.01$) of Thomayer's, Schober's, Stibor's and Otto's inclination and reclination tests and lateral flexibility, as well as the statistically significant improvement ($p < 0.01$) in overall muscular balance [1].

With regard to the evaluation of the results for individual indicators this study has several basic limitations. The first one is the deliberate selection of probands. This selection was based on the fact that there were probands closely focused on fitness sports and met the criterion of age, sex and performance homogeneity. The second limitation was the size of the research sample. The results obtained from the improbable selection cannot be considered representative and therefore we cannot generalize the results.

There is a probability of personal physical error, since measurements were not computerized.

Even though all the girls have been through the training process at the same time and with the same workload, we cannot avoid individual differences based on the degree of maturation and physical preoccupation.

Conclusions

When evaluating posture, we found that at least 22% of the subjects had excellent posture in all dimensions and only one subject (in the scapula dimension) had very poor posture. When evaluating overall posture, we diagnosed one subject with excellent posture, more than half with good posture, 22% with incorrect posture and in one subject we recorded very poor posture. The dimensions of the hips and shoulders (uneven position of the hips and shoulders) contributed most to the incorrect posture of all probands.

In all the tests for the detection of articular spinal motility we measured values within the norm, except for Otto's inclination test. As for the results of flatfoot measurements, we can also talk about positive results in the case of the right foot. In one subject we recorded the first degree of flatfoot in the right leg and in one case the third degree of flatfoot in the left leg. Overall, we recorded better results for the right than the left leg. We found different results when looking at the relationship between the sole of the foot and the individual dimensions of posture according to Klein and Thomas. Based on Kapandji's assessment we found a relationship between flatfoot and the spine dimension and between flatfoot and the hips and shoulders dimension. According to Srdečný et al., we found a relationship between the sole of the foot and the dimensions of the head, shoulder blades and abdomen. Statistical significance was also confirmed for the relationship between the sole of the foot and the dimensions of the spine, as well as the hips and shoulders. We can state that the probands most often showed a slight deviation from the individual standards of posture and also the quality of the sole.

We recommend in young girls to observe signs of flatfoot using podoscopy, which is a practical aid, thanks to which we can visually assess unilateral and bilateral flat feet. If the problem linking functional disorders in the motor system was not found in the area of the sole, this can be manifested in wrong posture and insufficient flexibility of the backbone. Flat feet can seriously impact overall body posture, which can lead to pain and injuries manifested not only in feet, but also elsewhere. In the case of flatfoot diagnosed in children participating in fitness training it is inevitable to immediately incorporate aimed exercises to form the arch of the sole and exercises promoting stabilization and regeneration of the backbone as secondary prevention measures.

Based on research concerning the supporting function of the leg, experts do not recommend long-term walking barefoot on a hard surface, since the child's leg could be overloaded and damaged.

We recommend including spinal mobilization exercises in the training unit to improve spine flexibility and core exercises to strengthen the corset muscles. We recommend exercises for spiral stabilization – the SM system, which by activating the muscle spiral through the arch of the foot improves the tone of the abdominal muscles and affects posture, the quality of the position of the lower limbs and the sole of the foot.

Conflict of Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Comparison of power, force, velocity and one repetition maximum of pull-ups performed by climbers on portable holds and a fingerboard

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Abstract
Introduction. **Climbing requires a great variety of movement and manoeuvres, many of which are based on the action of pulling the body up against the force of gravity. For this reason, pull-ups are among the most commonly performed exercises to develop upper body strength and power. However, since the traditional horizontal bar is not grasped as are climbing holds, climbers use more specific devices such as fingerboards and portable holds, the latter suspended from the bar.** Aim of Study. **This study was designed to investigate whether there was a difference in movement velocity, power and force, as well one repetition maximum (1RM) when pulling up on fingerboards or portable holds.** Material and Methods. **Sixteen male climbers volunteered to participate in the study (height: 176.4 ± 7.0 cm; weight: 72.4 ± ± 11.2 kg; age: 37.0 ± 10.0 years). Subjects performed pull-ups in the fingerboard (offering a stable suspension point) or portable holds (with single-point suspension offering freedom to move in different directions of the horizontal plane). Movement parameters (power, force, velocity of pull-ups) as well as estimated 1RM were recorded using a Gyko inertial sensor.** Results. **The analyses revealed that the maximum values of force, power and velocity of pull-ups were not significantly different between both devices. However, values for one maximum repetition were higher on the fingerboard than on portable holds ($p < 0.001$, $\eta^2 = 0.71$).** Conclusions. **On the basis of the study results we can assume that fingerboards (fixed in a stable way) may be relevant in developing maximal strength in pull-ups.**

KEYWORDS: strength, power, climbing, portable holds, fingerboard, pull-ups.

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Introduction

Rock and sport climbing are steadily increasing in popularity, with the latter being included in the programmes of the Olympic Games in Tokyo 2020 and Paris 2024. As a sport discipline, climbing involves three events: Lead, Speed and Bouldering. While physiological requirements are slightly different in each of them, all require forceful muscle contractions to move the climber's body upward on the wall [11]. For this reason, strength training takes a prominent place in the fitness preparation of sports climbers, covering the entire spectrum of movement speeds: from static and slow strength to explosive strength. It is especially true for the muscles of the upper body, in which various types of pull-ups are of particular importance, mainly performed on fingerboards. This device is a climbing-specific device designed to facilitate exercises such as pull-ups, dead hangs, lock-offs or front levers while simulating the gripping action of fingers on holds during climbing. Recent years have seen a rapid increase in the variety and number of such devices, among which portable holds, typically with a flexible single point suspension, have become particularly popular. They make it possible to perform very similar or even identical exercises as fingerboards, stimulating the same muscle groups and movement patterns as traditional fingerboards. Still, in contrast to the former they do not offer a stable hand-holding point, but provide the freedom to move in practically all directions in the horizontal plane. Theoretically, this situation presents a slightly different challenge in terms of intra- and intermuscular coordination, thus offering to some extent at least a different stimulus situation. However, to date few studies have addressed these issues. Those conducted so far have discussed the assessment of muscle electromyographic activity in various types of pull-ups, but not in the context of exercises that take into account the specificity of climbing training. For example, Snarr et al. [14] compared the EMG activity of the major muscles involved in the body pull-up movement, i.e. the latissimus dorsi, posterior deltoid, middle trapezius, and biceps brachii. Three variations of this exercise were compared: traditional pull-ups on a horizontal bar, pull-ups on a suspension device, and pull-ups on towels hanging over a bar. They found only one difference between these conditions with lower muscle activity of the middle trapezius while performing towel pull-ups compared to the traditional pull-up. In another study, Dickie et al. [4] compared muscle activity during pull-ups performed in the supinated grip, pronated grip, neutral grip and on ropes hanging over the bar, finding differences only between the concentric and eccentric phases of each pull-up.

However, the research mentioned above has limited applicability to the specifics of climbing training. Grabbing a bar, a towel or a rope differs from grasping climbing holds. This element is one of the factors determining whether an exercise meets the principle of climbing training specificity. It is achieved through such training means as fingerboards, which enable hand positions very similar to those, which climbers encounter in real climbing situations. Depending on how they are attached, they can offer either a stable or unstable hang point, which modifies the exercise conditions to simulate exercises performed either on a stable or unstable surface. While the effectiveness of performing different types of exercises depending on the type of surface (unstable vs. stable) has been the subject of research conducted by various authors [1, 2, 8, 10], to date few studies have investigated the effectiveness of pulling exercises on a stable or unstable suspension point [4, 14]. Additionally, to our best knowledge no research has been conducted in the context of training climbers.

Knowledge concerning such conditions is becoming increasingly crucial for climbers given new trends in the construction of routes for competitions, which require climbers to have a wide range of skills and motor abilities, from maximum strength to rate of force development and power. Although climbing requires a great variety of movement and manoeuvres, many of them are based on the action of pulling the body up against the force of gravity. For this reason, pull-ups are among the most commonly performed exercises to develop upper body strength and power. However, since the traditional horizontal bar is not grasped as climbing holds are, climbers use more specific devices such as fingerboards and portable holds, the latter suspended from the bar. This study aimed to investigate a potential difference in movement velocity, power and force, as well one repetition maximum (1RM) when pulling up on a fingerboard or on portable holds.

Material and Methods

Sixteen male climbers volunteered to participate in the study (height: 176.4 ± 7.0 cm; weight: 72.4 ± ± 11.2 kg; age: 37.0 ± 10.0 years). Their climbing level ranged from 6b+ to 8c max RP, and after conversion to IRCRA reporting [5] it reached (mean ± SD) 24.8 ± ± 5.4. As pulling up on a fingerboard, including loaded pull-ups, was previously regularly performed by the participants as a regular part of their training program, no familiarization session was included in the present study. Before testing, the participants were instructed to perform a warm-up consisting of a series of climbing circuits on a bouldering wall followed by a series of five dynamic pull-ups on a fingerboard and on portable holds.

Instruments

The Gyko inertial sensor system (Microgate, Bolzano, Italy) was used to register velocity (in m/s), force (in N) and power (in W) of pull-ups, as well as establish 1RM (in kg) pull-up.

This device was previously used in other studies, in which its reliability and validity were confirmed [6, 7, 13]. The device contains a three-dimensional accelerometer (range: ±2 G), a gyroscope (250°/s-25,000°/s) and a magnetometer (range: ±4800 μT). It provides recordings at a sampling frequency of 1 kHz. Participants had the Gyko sensor (dimensions: 53 × 51 × 23 mm, mass: 46 g) attached at the level of the body centre of mass on the back using an elastic belt provided by the manufacturer. During measurements the signals were transferred via a Bluetooth 4.0 to the Lenovo PC with the RePower software installed, following the criteria described by the manufacturer.

The pull-up tests were performed on a Witchboard Hard fingerboard (Witchholds, PL) using two 4 cm deep jugs, and Rock Rings portable holds (Metolius, USA), as presented in Figure 1. In both cases pull-ups were performed on the biggest jugs with similar dimensions.

Figure 1. Portable holds (left), fingerboard (upper, right), and Gyko inertial sensor (bottom, right). The ovals mark the holds on which the subjects performed pull-ups

The procedure of the test

After a warm-up the participants performed a series of dynamic pull-ups on a fingerboard or on portable holds, consisting of three repetitions with the aim to complete them as quickly as possible. After 1 minute of rest, those who performed the first series on the fingerboard pulled up on the portable holds and vice versa. A four-minute rest period was followed by 1RM pull-up trials, separated by 10 minutes of rest. Each trial consisted of three series of pull-ups with increasing load, from which the RePower software made a 1RM calculation. As practically all climbers knew the load, at which they could perform 5-6RM, the first series was started with this load. The intervals between the series in the trials were 2 minutes. To maintain maximum kinematic similarity between the pull-ups performed on the Rock Rings and the fingerboard, the subjects were instructed to keep their palms facing the dorsal surface towards the face during the former. To eliminate the potential interfering effect of the exercise order, half of the subjects started the trials with the fingerboard and the other half with the portable holds.

Statistical analysis

Descriptive statistics (means, standard deviations and 95% confidence intervals for mean values) were used to describe the data. The force, velocity and power values are presented as the maximum values of these parameters in a series of three dynamic pull-ups and the average of the three pull-ups comprising the series. Assumptions of normality and homogeneity of variance were tested with the Shapiro–Wilk and Levene's tests, respectively. Repeated measures ANOVA with the Bonferroni post hoc test was used to assess the differences between conditions. As a measure of effect size between both conditions eta-squared (η^2) was used with the following interpretation: 0.01 = small; 0.06 = medium; and 0.14 = large [9]. Statistical significance was accepted at $p < 0.05$. All analyses were conducted using the Statistica 13.3 software program (TIBCO Software Inc., Palo Alto, CA, USA).

Results

Descriptive statistics are presented in Table 1. Analysis of variance revealed the statistical significance of the device type (portable vs. fingerboard) in the case of 1RM pull up, with the fingerboard enabling greater 1RM values compared to portable holds $F_{(1.15)} = 36.6$, $p < 0.001$, $\eta^2 = 0.71$. On average, the value of 1RM was 8.5% higher (2.7 kg) for fingerboard pull-ups than for portable holds, with the effect size measure suggesting that the difference is of practical significance. When

Table 1. Values of force [N], power [W], velocity [m/s] and 1RM [kg] of pull-ups performed by climbers on the fingerboard and portable holds

	Fingerboard		Portable holds		Fingerboard/Portable holds comparison
	M (SD)	CI ± 95%	M (SD)	CI ± 95%	
Max force [N]	1762.3 (862.6)	1302.7-2222.0	1768.8 (890.9)	1294.1-2243.5	$F_{(1.15)} = 0.0$, $p = 0.962$
Max velocity [m/s]	1.43 (0.38)	1.23-1.63	1.41 (0.48)	1.15-1.66	$F_{(1.15)} = 0.3$, $p = 0.597$
Max power [W]	1775.7 (1103.9)	1187.5-2364.0	1837.7 (1351.3)	1117.6-2557.7	$F_{(1.15)} = 0.2$, $p = 0.681$
Mean force [N]	1492.3 (636.2)	1153.3-1831.3	1519.6 (704.9)	1144.0-1895.2	$F_{(1.15)} = 0.1$, $p = 0.811$
Mean velocity [m/s]	1.36 (0.40)	1.15-1.57	1.28 (0.40)	1.06-1.49	$F_{(1.15)} = 3.7$, $p = 0.075$, $\eta^2 = 0.20$
Mean power [W]	1531.4 (885.6)	1059.5-2003.3	1336.3 (851.6)	882.5-1790.0	$F_{(1.15)} = 8.7$, $p = 0.010$, $\eta^2 = 0.37$
1RM [kg]	34.3 (12.2)	27.8-40.8	31.6 (11.8)	25.3-37.9	$F_{(1.15)} = 36.6$, $p < 0.001$, $\eta^2 = 0.71$

comparing maximum values obtained at the dynamic pull-ups on a fingerboard and on portable holds, no significant differences were observed in force ($p = 0.962$), velocity ($p = 0.597$) or power ($p = 0.681$). However, as shown by the analysis of variance, there was a tendency towards greater mean velocity across three pull-ups performed on a fingerboard compared to portable holds and significantly greater power output of pull-ups performed on the former.

Discussion

The main purpose of this study was to compare velocity, power, force and 1RM values during pull-ups performed on both types of devices. Despite their similarity in terms of hand placement (type of grip, its depth, etc.), they offer different exercise conditions, being in a sense the equivalent of exercises performed on a stable and unstable surface [14]. While a number of studies were conducted to compare the effects of exercising on stable vs. unstable surfaces [2, 3, 12], most of them focused on activities performed in supported positions. Their results have limited applicability to exercises performed in overhanging positions, which predominate in climbers' training. In this study it was hypothesised that training on the fingerboard would promote greater 1RM values, while portable holds would promote greater velocity of pull-ups and higher power output. The recorded results confirmed this hypothesis, with the subjects obtaining 1RM values on the fingerboard on average about 8.5% higher than during pull-ups on the portable holds. What is noteworthy, virtually every subject achieved a higher score, with individual differences ranging from 1 to 6 kg. Nevertheless, the other variables (velocity, power and force) were similar during pull-ups on portable holds and pull-ups performed on a fingerboard. Only in the case of power, the difference between both conditions was statistically significant, although small considering the effect size.

The information gained from the research can provide practical guidance for coaches and athletes involved in climbing. Any sports training session aims to maximise fitness and the right choice of exercises and equipment should make this possible. Since a wide variety of equipment for performing pull-ups is currently available for climbers, they are faced with the dilemma which equipment to choose to serve the assumed training goals best or, conversely, whether they are equivalent to each other in achieving specific goals. Our study suggests that the differences between fingerboards and portable holds are insignificant or small in most of the movement parameters assessed, except for the 1RM value, which was significantly greater on the fingerboard. The higher values of the external load, with which the subjects could perform the maximum pull-up repetition suggest that this apparatus should be the preferred choice in exercises aimed at developing maximal strength in pull-ups.

There are a few limitations of this study that need to be considered when interpreting its results. Firstly, is connected with the relatively small number of subjects, which limits data analysis, since the participants could not be further divided into subgroups of different strength and climbing levels. Secondly, climbers were asked to keep a similar position of the hands on the holds while performing pull-ups, which in the case of portable holds, where they spontaneously undergo a slight rotation, required special attention from the participants. This fact may have had some influence on the way they performed their pull-ups. Rock Rings are only one of many available types of portable holds, thus other types of such devices should also be investigated to see if the relationships found are more universal.

Conclusions

On the basis of this study it may be assumed that fingerboards (fixed in a stable way) may be relevant in developing maximal strength in pull-ups. Further research in this area, especially experimental, is needed to confirm such a conclusion.

Conflict of Interests

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

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Relations of muscle strength and body mass when performing different vertical jumps

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Abstract
Introduction. **Sports result largely depends on body dimensions and the development of motor skills.** Aim of Study. **The aim of the study was to examine the relationship between body mass and muscle strength test results when performing different variants of vertical jumps.** Material and Methods. **Sixty selected senior basketball players participated in the study. According to the criterion of the position played in the team, the respondents were divided into two groups. One group consisted of external players (n = 30), while the other group comprised internal players (n = 30).** Results. **In both groups of subjects, low correlation coefficients were obtained between body weight and results of indirect muscle strength assessment tests (0.00; –0.05; –0.00; –0.02), as well as weak correlation coefficients between results of direct muscle strength assessment tests and body weight (0.44; 0.36; 0.41; 0.38). In the group of external players in the tests for the direct assessment of muscle strength allometric exponents b = 0.82 and b = 0.74 were recorded, while for internal players in these tests allometric exponents b = 0.73 and b = 0.72 were obtained. Tests for the indirect assessment of muscle strength in the group of external players gave allometric exponents b = 0.09 and b = –0.00, while in the group of internal players the exponents were b = –0.10 and b = –0.25.** Conclusions. **This study showed that the results in the tests for the direct assessment of muscle strength when performing fast movements are dependent on body mass, while those in tests for the indirect assessment of muscle strength when performing fast movements do not depend on body mass.**

KEYWORDS: basketball players, body dimensions, allometric scaling, fast movements.

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Introduction

The sports result largely depends on the athlete's body dimensions and the development of motor skills. Successful movement and solving motor tasks are influenced not only by body dimensions, but also by other factors, such as gender, age and body composition [4, 10, 14, 18, 22, 30, 32]. Of these factors, the influence of body dimensions on motor ability needs to be especially emphasized, because physical growth and development largely determine the level of development of motor and functional abilities [12]. Previous studies concerning all body dimensions specifically analyzed the effect of body weight and body height on motor abilities [12-34]. The athletes with larger body dimensions show greater muscular strength and they will overcome a higher external load compared to those with smaller body dimensions. It is common to say in a description of a body that it is twice as large as another, making no distinction in terms of body length, surface area and volume. At the same time, the important fact is forgotten that the lengths, surface areas and volumes for bodies of similar dimensions do not scale proportionally. For the two bodies, being geometrically similar, but of different dimensions, it cannot be claimed that they are the same, because the ratio of surface area and volume changes significantly with the dimension of the body [2]. Initially, studies were conducted that referred to the effect of body dimensions on strength in weightlifters. Hoffman researched the influence of body weight on muscle strength in the 1930s and came up with the so-called Two-thirds power law. Comparing the abilities of weightlifters characterized by different body dimensions, he determined the so-called Hoffman formula. Ten years later, Austin considered the $m^{2/3}$ exponent to be insufficiently accurate, thus he set up the Austin formula, which involved the $m^{3/4}$ exponent [2]. The unexpected results in weightlifting were explained by those researchers by scaling strength with body weight. In the lower weight categories the weight of the lifted load increases proportionally with the body weight of competitors, while this growth is significantly slower in heavier competitors. The reason lies in the scaling of muscle strength with $m^{2/3}$, i.e. heavier competitors, in relation to their own weight, are relatively weaker than lighter competitors. More recently the effect of the dimensions of the locomotor system on human motor abilities has been investigated in many studies [12-34]. The influence of body dimensions on the mechanics of movements is referred to as scale effects, thus bringing a mechanical quantity that describes the movement in connection with a certain dimension of the body is called scaling [12]. Among researchers opinions are divided when it comes to the effect of body dimensions on motor abilities. Some authors consider body dimensions and motor abilities to be linearly dependent and in the normalization of results they use the method of proportional scaling, with the obtained results presented per kilogram of body weight [9, 10]. On the other hand, other authors are of an opinion that type of normalization is not adequate and in a number of studies they have proven the nonlinear dependence of body dimensions and motor abilities [14-25]. There are two models in normalizing the results. The theoretical model in examining the influence of body dimensions on the locomotor system is based on the assumption that two bodies are basically the same, with differences found only in their dimensions. It is based on the concept of geometric similarity and is referred to as geometric scaling [1]. When the results of research are normalized in relation to body weight by applying proportional scaling, different exponents are obtained in different groups of motor ability tests. Since the topic of this paper is connected with testing the effect of body weight on the manifestation of muscle strength when performing fast movements, only exponents for normalization of results in tests of direct and indirect assessment of muscle strength when performing fast movements will be presented. Two models are most often used in the normalization of results. According to the theoretical model, tests for the direct assessment of muscle strength are normalized with $m^{2/3}$ and the theoretically predicted value for results normalization is b = 0.67 [1, 7]. Tests for the indirect assessment of muscle strength when performing fast movements do not depend on body dimensions. If the movement is performed with a maximum jump, the test results are proportional to the surface area of the muscle and the length of its shortening, and they are inversely proportional to body weight. In a study of Marković and Jarić [19], recorded results indicate that strength during the vertical jump is related to body dimensions, while the jump height in the same tests remained independent of body dimensions. It should be noted that some studies have confirmed that transverse body dimensions, relative to body size, grow faster than longitudinal body dimensions. This assumption is confirmed by the theory of elastic similarity. According to this theory, muscle strength and power should be proportional to $m^{0.75}$, not to $m^{0.67}$ [15, 16, 20, 25-27]. In order to more precisely normalize the results of the tests, an experimental model, known in practice as allometric scaling, is often applied in practice [14, 15, 34]. By applying allometric scaling, the obtained results of motor tests do not depend on body dimensions. The basic idea of this study arose from the assumption that the effects of scaling are manifested differently in people of different body dimensions. Nevill et al. [25] when comparing well-trained athletes with physically inactive individuals confirmed that body composition between subjects was not geometrically similar. They concluded that in both groups of subjects body circumferences and body segments, in locations of greater muscle mass and adipose tissue, grow at a faster rate than that predicted by geometric similarity. On the other hand, in the area of the head and joints the growth of the volume of the body segments is slower than the geometric similarity predicts. Bazett-Jones et al. [2] noted a test dependence of muscle force and torque on body mass of different allometric exponents in men and women. Applying the obtained exponents he normalized the results and successfully neutralized the influence of body weight on the manifestation of motor abilities. Starting from the assumption that the effects of scaling are manifested differently in people of distinctly different narrow dimensions, the aim of this study is to examine the relationship between body mass and muscle strength tests when performing different vertical jumps in two groups of basketball players of different body dimensions.

Material and Methods

Study participants
A total of 60 senior elite basketball players participated in this study. They were divided into two equal groups based on the position they play in the team. One group of basketball players consisted of 30 outside players (11 pointguards, 10 shooting guards and 9 small forwards) with an average age of 25.21 ± 4.11 years, body mass 86.91 ± 7.78 kg, body height 191.38 ± ± 6.22 cm and body fat percentage 10.83 ± 3.27% (Mean ± SD). The other group comprised 30 inside players (14 power forwards and 16 centers) with an average age of 24.10 ± 4.28 years, body mass 102.28 ± ± 6.73 kg, body height 204.16 ± 3.37 cm and the percentage of body fat 13.20 ± 3.02% (Mean ± Std.Dev). Regarding the research methodology it is important to note that the recommendation is that the number of participants in such research should be 5-10 times higher than the number of tested variables [21]. In this study, four variables were tested on a sample of thirty subjects, which satisfies the prescribed recommendations. All the participants have been playing basketball professionally and participate in the highest ranking basketball competitions in Bosnia and Herzegovina. The criteria for inclusion were as follows: players who joined the first team for at least six months, players who played at least one half-season before testing, all players went through the preparation period with the team, without injuries in the last six months. Exclusion criteria were as follows: players in the recovery phase from some form of acute or chronic injuries, players in the process of rehabilitation and basketball players who did not complete the entire preparation period.

Study organization
Testing was performed by the same experienced examiner at the Laboratory for isokinetic testing, the Faculty of Physical Education and Sport in Banja Luka, Bosnia and Herzegovina. The laboratory was air-conditioned and room temperature was held between 22-24ºC. Testing was performed between 9.00 am and 14.00 pm. The morphological characteristics of the subjects was assessed on the basis of data obtained by measuring body height, body mass and percentage of body fat. Body mass (kg) and subcutaneous adipose tissue (%) of the subjects were measured by the method of bioelectrical impedance (TANITA BC418) accurate to 0.1 kg, while for body height (cm) an altimeter (Seca, Germany) accurate to 0.5 cm was used. The measurements were performed in accordance with the instructions of the International Association of Anthropometric Measurements (ISAK). A force platform (Globus Ergo Tesys System 1000, Force plate – Mega twin plates, Italy) was used to assess muscle strength when performing a vertical jump. In the vertical jump tests the countermovement jump (CMJ) and squat jump (SJ), the maximum jump height (cm) and the maximum displayed power (W) in the concentric phase of the jump (CMJP and SJP) were measured. Test results expressed in the maximum jump height in centimeters (cm) represent an indirect estimate of muscle strength (CMJ; SJ), while test results obtained in the concentric phase of a vertical jump expressed in watts (W) represent a direct estimate of muscle strength (CMJP; SJP). After a ten-minute warm-up on a bicycle ergometer (Monark) and dynamic stretching, the subjects performed two tests in three attempts, with a 10-second break between repetitions. The break between tests was 5 min. The best achieved values in the tests were taken for analysis. The CMJ test was performed with isolated hands on the hips. The subject was in a normal upright position, after which he descended to the semi-squat position (the angle of the thighs and lower legs was approximately 90°) and without stopping, at the point of changing the direction of movement, performed the maximum vertical jump [11]. The SJ test was performed with isolated hands on the hips. The subject was in a normal upright position, after which he descended to the semi-squat position (the angle of the thighs and lower legs was approximately 90°), maintained this position for three seconds, and after the signal performed a maximum vertical jump [11]. To obtain data in the CMJP and SJP test a force platform was used, where muscle strength was calculated as the product of the vertical component of the reaction force and the velocity of the center of body mass. The jump height in the CMJ and SJ tests was determined as the displacement of the center of mass of the body calculated from the vertical component of the reaction force and body mass. Based on the duration of the flight, the maximum jump height was calculated in the CMJ and SJ tests (the flight time method). A standard formula was used to calculate the jump height ($h = v_{take\text{-}off}^2/2g$). Muscle strength in the tests was expressed as the product of the vertical component of the ground reaction force (GRF) and the velocity of the center of mass of the body ($P = F \times v$) [1]. Measurement on the force platform requires precise adherence to the test technique (both feet should leave and touch the platform at the same

time, the knees in the jump take a stretched position, the torso remains in the stretched position). According to the theory of geometric similarity, muscle strength and power are proportional to the cross-sectional area of the muscle, which is proportional to body weight graded to 2/3 (b = 0.67). An allometric scaling model was used to normalize muscle strength relative to body mass. The equation representing allometric scaling is

$$a = S / m^b \quad (1)$$

where (a) the index of motor abilities, (S) motor ability, (m) body mass, and (b) the allometric exponent [13]. By applying equation (1) each motor ability (S) can be represented as a function of body dimensions (m):

$$S = a \cdot m^b \quad (2)$$

where (a) is a constant multiplier, and (b) is an allometric exponent.
By logarithmic transformation of equation (2), the regression line equation is obtained:

$$log(S) = log(a) + b \cdot log(m) \rightarrow \quad (3)$$

where parameter (a) represents the segment and parameter (b) is the slope coefficient of the regression line. Using regression analysis, the method of least squares, the values of parameters (a) and (b) are calculated, which determines the relationship between motor abilities and body dimensions.

Statistical analysis
The obtained data were processed by descriptive and comparative statistical procedures. Within the descriptive statistics for all variables are determined, i.e. arithmetic mean and standard deviation. Within comparative statistics the following were applied: simple linear regression analysis (least squares method) to determine parameter a, which represents the segment, and parameter b, which represents the slope coefficient of the regression line, based on which the correlation between the results of motor skills and body mass tests is assessed. All the collected data were processed using the statistical program Statistics SPSS version 20.0.

Ethical approval
The research was approved by the Ethics Commission of the Faculty of Sports and Physical Education, University of Banja Luka in accordance with the Declaration of Helsinki [35].

Informed consent
All the participants were first informed about the study, the purpose and goal of the research and possible consequences were explained to them. Also the procedure and the course of the testing itself were explained to the participants. Prior to the survey, each participant signed a consent form to participate. For this research the consent and approval of the head coach and the president of the club were obtained and after that testing was started.

Results
Table 1 shows the basic descriptive parameters (Mean ± ± SD) of vertical jump variables for basketball players divided based on their positions in the team.

Table 1. Vertical jumps of basketball players divided based on their positions in the team

Variables	Outside players	Inside players
	Mean ± SD	Mean ± SD
CMJ (cm)	36.53 ± 4.56	31.83 ± 2.79
CMJP (W)	4494.12 ± 735.50	4810.90 ± 587.65
SJ (cm)	35.26 ± 4.31	30.33 ± 2.89
SJP (W)	4415.94 ± 732.80	4635.60 ± 568.30

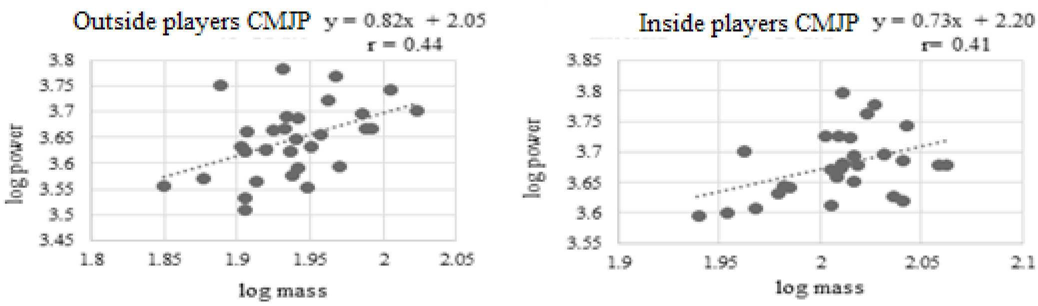
Note: CMJ – countermovement jump, CMJP – countermovement jump power, SJ – squat jump, SJP – squat jump power

Table 2 presents the relationship between the logarithmic results of tests for motor abilities of outside and inside players of senior age with body weight. In both groups of subjects low correlation coefficients (0.00; –0.05; –0.00; –0.02) were obtained between body mass and indirect muscle strength assessment tests, as well as moderate correlation coefficients between direct muscle strength assessment tests and body weight (0.44; 0.36; 0.41; 0.38).

Table 2. Correlation of results from tests of motor abilities of outside and inside players with body weight

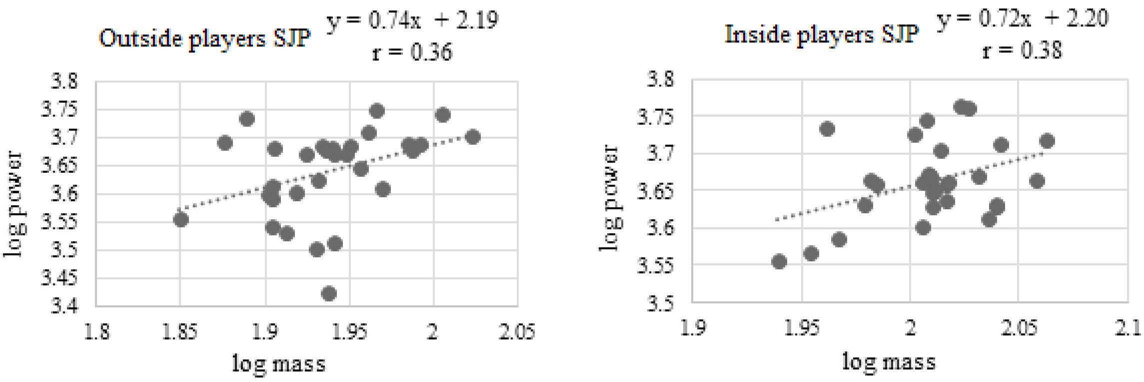
		Outside players				Inside players			
		CMJ	CMJP	SJ	SJP	CMJ	CMJP	SJ	SJP
m	*a*	1.37	2.05	1.56	2.19	1.70	2.20	1.98	2.20
	b	0.09	0.82	–0.00	0.74	–0.10	0.73	–0.25	0.72
	r	0.00	0.44*	–0.05	0.36*	–0.00	0.41*	–0.02	0.38*

Note: CMJ – countermovement jump, CMJP – countermovement jump power, SJ – squat jump, SJP – squat jump power, *a* – segment, *b* – slope coefficient of regression line, m – body mass, *r* – correlation coefficient
* $p < 0.05$



Note: CMJP – countermovement jump power

Figure 1. Relationship between logarithmic results of body mass and manifested muscle strenght in concentric phase of the countermovement jump in outside and inside players



Note: SJP – squat jump power

Figure 2. Correlation between logarithmic results of body mass and expressed muscle strenght in the concentric phase of squat jump in outside and inside players

In the group of outside players allometric exponents b = 0.82 and b = 0.74 were obtained in the tests for the direct assessment of muscle strength (Figure 1, Figure 2). In inside players allometric exponents b = 0.73 and b = 0.72 were obtained in direct muscle strength assessment tests (Figure 1, Figure 2). Regarding the tests for the indirect assessment of muscle strength in the group of outside players allometric exponents b = 0.09 and b = –0.00 were recorded, while in the group of inside players it was exponents b = –0.10 and b = –0.25 (Table 2).

Figures 1 and 2 show the correlation between the logarithmic results of body mass and the expressed muscle strength in the concentric phase of the CMJ and SJ in outside and inside players. The slope coefficient of the regression line corresponds to the allometric exponent that determines the relationship between muscle strength and body mass.

Discussion

Using an experimental model in data normalization allometric exponent b was determined, which shows the correlation of test results for different vertical jumps and body weight. The basic assumption is that muscle strength manifested in the concentric phase of vertical jumps is dependent on body mass, while the height of vertical jumps is independent of body mass. When testing the relationship between motor skills and body dimensions, attention must be paid to other factors, such as gender, age, physique and level of physical fitness [13]. Guided by these recommendations, the participants in our study did not differ significantly in terms of age, they are of the same sex, approximately similar level of training, while body composition and low percentage of adipose tissue did not negatively affect the manifestation of motor skills. This study involved selected basketball players, whose body height, body weight and percentage of adipose tissue approximately correspond to the values of top European basketball players [7, 28, 33]. The study results in the CMJ and SJ tests indicate that in both groups of the participants low correlation coefficients were obtained between body mass and indirect muscle strength assessment tests, as well as moderate correlation coefficients between direct muscle strength and body mass assessment tests (Table 2). The obtained results are consistent with the results of other researches. Nedeljković et al. [22] recorded moderate correlation coefficients (from 0.21 to 0.56) between body weight and various motor ability tests. In all muscle strength tests a statistically significant association with body weight was confirmed. In the same study an average value of allometric exponent b = 0.55 was obtained. Another study reported a low correlation coefficient between the tests for the indirect assessment of muscle strength and body mass (–0.03) [18]. In the same study in the tests for the direct assessment of muscle strength when performing rapid movements a slightly lower allometric exponent (b = 0.57) was obtained compared to the theoretically predicted value (0.67). In the continuation of the research of the same problem, Marković and Jarić [17] tested the connection between the tests for the direct assessment of muscle strength in the vertical jump and body weight before and after the normalization of the data. Prior to normalization, a moderate positive association between muscle strength and body mass was observed. After data normalization the correlation coefficients decreased. Regarding allometric exponents in the CMJP test, a smaller allometric exponent was recorded for inside players (b = 0.73) compared to outside players (b = 0.82). This result can be explained by the higher proportion of adipose tissue in the body composition of players playing in inside positions. Folland et al. [5] confirmed that with the increase of the fat component in the human body the value of the allometric exponent recorded in relation to body weight decreases. Different allometric exponents between the tested groups can also occur due to significant differences in body weight and body height of outside and inside players. In the SJ test very similar allometric exponents were obtained. For outside players exponent b = 0.74 was obtained, while for inside players it was b = 0.72. In both groups of subjects different allometric exponents were recorded in relation to the theoretically predicted value for this group of tests (b = 0.67). Taking into account the results in both tested groups and both vertical jump tests, the mean value of the allometric exponent is b = 0.75, which is slightly higher than the theoretically predicted value determined by the theory of geometric similarity. It should be emphasized that the obtained mean value of the exponent coincides with the value predicted by the theory of elastic similarity ($m^{0.75}$). Discrepancies between the values of allometric exponents and the theoretically predicted value (0.67) may be the result of markedly different body dimensions of the examined basketball players in relation to the average population, which was most often the sample in such research. Regarding the tests for the indirect assessment of muscle strength in the CMJ test exponents b = 0.09 for the group of outside players and b = –0.10 for the group of inside players were obtained. In the SJ test exponent b = –0.00 was recorded in the group of outside players, while b = –0.25 was obtained in the group of inside players. The mean value in both tests and in both tested groups is b = –0.08, which is very close to the theoretically predicted value of b = 0. As expected for this group of tests, it was confirmed that the results do not depend on body weight and that they do not need to be normalized in order to eliminate the influence of body dimensions. Marković and Jarić [18] used an experimental approach to normalize the tests for the indirect assessment of muscle strength in relation to body weight to obtain a mean value of the allometric exponent b = 0.07, which is approximately the mean value of the exponent obtained in our study. Although some research results indicate a moderate positive association between movement speed and body dimensions [31], the results of our study are consistent with the data reported by Nedeljković et al. [22], in turn confirming the findings of Marković and Jarić [18] that indirect muscle strength assessment tests when performing rapid movements does not depend on body mass.

Conclusions

Among other factors, body dimensions significantly affect the manifestation of motor abilities. The influence of body mass on motor abilities was most often examined. In both groups a nonlinear relationship was confirmed between body mass and results in direct muscle strength assessment tests when performing vertical jumps. On the other hand, there was no correlation between body mass and muscle strength in the tests for the indirect assessment of muscle strength when performing the same tests. In the tested groups different allometric exponents were obtained in the tests for the direct assessment of muscle strength. The same exponents also differed from the theoretically predicted value for this group of tests. In the tests for the indirect assessment of muscle strength, approximately similar allometric exponents were obtained, which did not differ in relation to the theoretically predicted value. This study represents only a small part of the problem related to the effects of scaling. A special contribution of this research is that selected basketball players were tested, with different body dimensions and different body dimensions in relation to the average population. The conclusions of this study can be used in future research to examine the effect of body dimensions on different groups of motor skills tests.

Conflict of Interest

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

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Correlations between anthropometric characteristics and physical fitness profile in different age and level categories of soccer players

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Abstract
Introduction. **Determination of the fitness profile in soccer players of different categories using the field test is particularly useful. It can be used to assess the physical condition of other soccer teams, but also to show differences between the categories.** Aim of Study. **This study aimed to compare anthropometric and physical fitness profiles of U10, U12, U14, amateur and semiprofessional male soccer players, as well as find correlations between the measured indicators.** Material and Methods. **Subjects included 228 athletes. Anthropometric characteristics and field fitness parameters were measured.** Results. **Differences were observed in height, weight and BMI of the athletes between all the groups ($p < 0.001$) except for the amateur and semiprofessional groups ($p = 0.091$). In fitness tests, groups of semiprofessional and amateur players showed better performance than all the groups of developmental ages. Also, semiprofessionals performed better than amateurs in all the tests except for the sit and reach and abdominal test. At the developmental ages the U14 differed from the U10 and U12 in terms of 30 m, LJ and T-tests, while no other differences were observed. In the case of the correlations it is characteristic that the percentage of body fat is negatively related to LJ at the developmental ages and to SJ in adults. The CMJ was the fitness test that showed the greatest relationships with anthropometric characteristics and other tests.** Conclusions. **In conclusion, this study presents the profile of the physical condition for players of developmental ages (non-elite), amateurs and semiprofessionals. The improvement in performance depends on training, but also on biological maturation and development. In adults the different level of athletes is shown in terms of all the physical abilities tests, with semiprofessionals performing better. Greater specialization of training contents (increase in volume and intensity at the highest level) causes more effective adaptations in soccer players.**

KEYWORDS: field tests, anthropometric characteristics, youth soccer players, fitness profile.

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Introduction

Adult soccer is an intermittent sport that includes activities with low and high intensity. In high-level soccer players run a total distance of 10-13 km during the match. Running at high intensity is about 10% of this distance [3]. At the developmental ages the total distance covered during matches ranges from ~4 km for the under 10-year old team (U10) up to 8 km for the under 16-year old team (U16) [18]. At the same time, players at all levels perform many other activities during the match, such as accelerations, decelerations, changes of direction and jumps [17].

At the developmental ages physical development and maturation can significantly affect performance [8]. Frequently coaches and sports scientists look for norms to compare and evaluate the physical performance of their players. However, certain factors such as ethnicity, level and age can affect these norms (e.g. anthropometric characteristics).

Physical performance in soccer is a general term that includes several abilities and cannot be described by a single parameter [14]. For this purpose several different fitness tests (laboratory and field) are used to form an overall picture of the player's physical performance. Thus, laboratory measurement, which is the most accurate method, requires the use of expensive equipment, well-trained personnel and a lot of time for measuring large groups of athletes such as that of a soccer team. All the reasons mentioned above lead to the development of different field tests to estimate physical abilities [1, 12] which can be used to measure a large number of players in less time, using much less equipment.

Thus, the first aim of the study was to compare the anthropometric characteristics, speed, horizontal and vertical jumping ability, flexibility, agility, strength of the abdominal and aerobic ability in amateur and semiprofessional Greek soccer players, as well as the developmental categories: the under 10-year old team (U10), under 12-year old team (U12) and under 14-year old team (U14). Another purpose was to investigate correlations between tests and compare these correlations between categories. It was hypothesized that anthropometric and fitness measures would increase across the age and level groups. Also, it was hypothesized that many correlations will be observed between the fitness tests.

Material and Methods

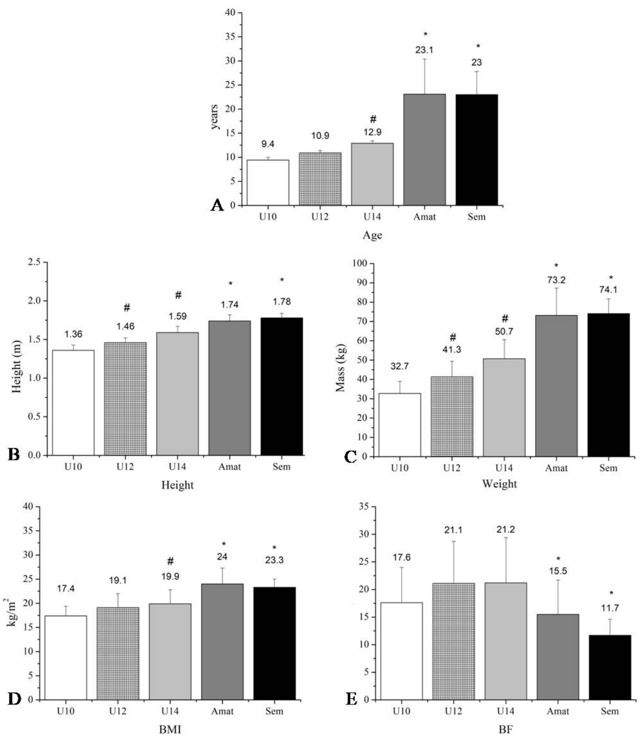
Design

This was a cross-sectional comparative study aimed at characterizing the anthropometrical and fitness profiles of soccer players across three different developmental age groups (U10, U12, U14), amateur and semiprofessional levels (n = 228). Assessments included height, body mass, body mass index, body fat percentage (4 skinfold), maximal sprint speed, jump height, jump distance, agility, flexibility, abdominal endurance and aerobic capacity. Between the developmental ages and adults there were some changes in the tests, in which no comparisons were made between them. More specifically, in the developmental ages the long jump, the T-test and the Yo-Yo intermitted endurance test level 1 vs the squat jump, to the Illinois agility test and to the Yo-Yo intermitted recovery test level 1 used in adults. Measurements were carried out in the pre-season period, in the afternoon (18:00-21:00), on a synthetic soccer field across two testing days to avoid fatigue and any circadian variation in performance [20]. Participants were advised to abstain from vigorous exercise for 24 hours before the testing.

Subjects

Male soccer players (n = 228) from Greek soccer teams participated in this study. The inclusion criteria to participate in the study were as follows: 1) not to have musculoskeletal injuries for ≥6 months prior to the study, 2) having participated in ≥80% of training sessions of the last year, and 3) not to be taking any medication. All participants and their parents (for the youth) were informed of the potential risks and benefits of the study and consent was signed by them or their parents. The study was performed in the spirit of the Helsinki Declaration.

Twenty players were members of the U10, 25 belonged to U12, 63 belonged to U14, 36 belonged to the senior's amateur team and 60 belonged to the senior semiprofessional team. All players were familiarized with the procedures two weeks before the testing day. Participants' characteristics are shown in Figure 1.



* significant differences between adults (amateur, semiprofessional) and groups of developmental ages;
# significant differences between U14, U12 and U10 groups

Figure 1. Anthropometric characteristics. A – age of the subjects; B – height of the subjects; C – weight of the subjects; D – BMI of the subjects; E – body fat of the subjects

Procedures

Anthropometric measurements

Body mass was measured to the nearest 0.1 kg using an electronic digital scale with the participants wearing only their underclothes and being barefoot. Standing height was measured to the nearest 0.1 cm (Seca 220e; Hamburg, Germany). Body fat percentage was estimated based on the sum of four (biceps, triceps, suprailiac, subscapular) skinfold thicknesses measured with a specific caliper by Lafayette, Ins. Co., Indiana, on the right side of the body as described [24]. Estimation of the body density was calculated according to the equation proposed by Durning and Rahaman [7] for male adults older than 16 years and estimated by the equation of Siri [23].

Fitness tests

Fitness tests were completed in the following order: squat jump (SJ) or long jump (LJ) (for youth), countermovement jump (CMJ), 30 m linear sprint, and the Illinois agility test or T-test (for youth). The next day performed: abdominal endurance, flexibility (sit and reach test), and Yo-Yo intermitted recovery test level 1 (YYIR1) or Yo-Yo intermitted endurance test level 1 (YYIE1) (for youth). The better time of two attempts was considered as the fitness test score except for the Yo-Yo tests where they performed only one attempt. The interval between the tests was fuel. At the beginning of each testing session soccer players performed a 15-minute warm-up and at the end a 10-minute cool-down period. During the tests all the participants consumed water ad libitum to ensure proper hydration.

Speed testing

A 30 m sprint test was used to measure speed performance. Sprint testing was performed with the participants wearing soccer shoes on the synthetic grass of a soccer field. After a 5-second countdown the participants ran in front of two infrared photoelectric gates (Microgate, Bolzano, Italy) that recorded times at each gate. The participants sprinted from a standing starting position with the toe of the front foot approximately 0.3 m behind the first gate. Photocells were placed 0.6 m above the ground (approximately at the hip level) to capture the movement of the trunk rather than a false signal because of a limb motion [15]. The coefficient of variation for test–retest trials was 3.8%.

Standing long jump testing

The participants adapted a starting standing position with their feet at shoulder width (behind a line marked on the ground) and their hands free. The participants executed a countermovement with their legs and with a hand movement and then jumped horizontally as far as possible, as described [9]. The horizontal distance between the starting line and the heel of the rear foot was recorded with a tape measure. The coefficient of variation for test–retest trials was 3.9%.

Vertical jump testing

The participants performed two jump tests: (a) SJ: participants, from a stationary semi-squatted position (90^o angle at the knees), performed a maximal VJ; (b) CMJ: participants, from an upright standing position, performed a fast-preliminary motion downwards by flexing their knees and hips followed by an explosive upward motion by extending their knees and hips. All the tests were performed with the arms akimbo. The VJ height was measured with the Chronojump Boscosystem (Chonojump, Barcelona, Spain). The coefficients of variation for the test–retest trials were 3.0 and 3.8% SJ and CMJ, respectively.

Agility: T-test

The participants performed the T-test: Subjects began with both feet behind the starting point A. At their own discretion, each subject sprinted forward 9.14 m to point B and touch the base of a cone with the right hand. They then shuffled to the left 4.57 m and touched the base of a cone (C) with their left hand. Subjects then shuffled to the right 9.14 m and touched the base of a cone (D) with their right hand. They then shuffled to the left 4.57 m back to point B and touched the base of the cone with their left hand. Subjects then ran backwards, passing the finish line at point A. At point A an infrared photoelectric gate (Microgate, Bolzano, Italy) was placed which recorded the time of each attempt [22].

Agility: Illinois test

The Illinois agility test was set up with four markers forming a square area of 10 × 5 m. The start and finish gates were positioned at two consecutive angles of a square area, while two markers were positioned on the opposite side to indicate the two turning points. Four other markers were in the center, positioned at an equal distance apart (3.1 m). Each participant had to run as quickly as possible from the start gate, follow a planned route, and slalom through the markers without knocking them down or cutting over them. From a standing position, each athlete sprinted 10 m on command and returned to the starting line, then had to swerve in and out of the markers, perform another sprint of 10 m and complete the test by running to the finish gate. The photocells at the start and finish gates recorded the test time. A graphic representation of the test is shown in Figure 2.

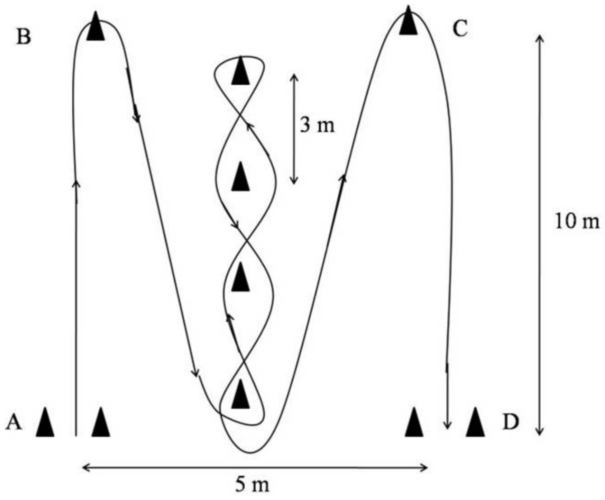


Figure 2. Graphic representation of the Illinois agility test

Flexibility testing
The participants performed the sit and reach test to evaluate flexibility of the lower back and hamstring muscles. We used the Eurofit manual that suggests having 15 cm at the level of the feet. The participants were sitting barefoot on the floor with legs stretched out straight ahead. The soles of the feet were placed flat against the box. Both knees were locked. With the palms facing downwards and the hands on top of each other or side by side, the subjects were reached forward along the measuring line as far as possible.

Abdominal endurance test
The participants performed as many sit-ups as they could in 30 seconds. They were instructed to lie on the mat with the knees bent at right angles, with the feet flat on the floor and held down by a partner. The fingers were to be interlocked behind the head. On the command ‘Go’, the participants raised the chest so that the upper body was vertical, then returned to the floor. This was continued for 30 seconds. For each sit up the back had to return to touch the floor. The maximum number of correctly performed sit ups in 30 seconds was recorded. The sit up was not be counted if the subjects failed to reach the vertical position, failed to keep their fingers interlocked behind their head, arch or bow their back and raise their buttocks off the ground to raise their upper body, or let their knees exceed a 90-degree angle.

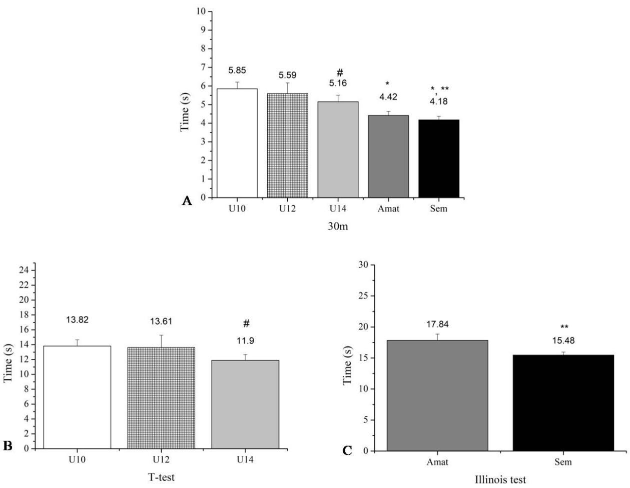
Statistical analysis
Data are presented as means ± SD. Furthermore, for fitness variables the confidence intervals (CI) were given. Data normality was verified with the 1-sample Kolmogorov–Smirnoff test; therefore, a nonparametric test was not necessary. A one-way analysis of variance (ANOVA) was used to compute any differences in the subjects’ performance on the tests. Wherever a significant difference was found, the post hoc Bonferroni test was applied. Pearson’s two-tailed correlation analysis determined relationships between the anthropometric characteristics and fitness tests. The level of significance was set at $p < 0.05$. The SPSS version 25.0 was used for all analyses (SPSS Inc., Chicago, IL, USA).

Results
The confidence intervals for the variables are presented in Table 1.
Differences were observed between all the groups for height, weight and BMI ($p < 0.001$) with the exception of the amateur and semiprofessional groups ($p = 0.091$), where the semiprofessionals were slightly taller and lighter. In the developmental categories the values of characteristics increased with age. The characteristics are presented in Figure 1.
In the percentage of body fat, semiprofessionals had the lowest value followed by amateurs. Differences were observed between the adult groups and the developmental age groups ($F = 21.121$, $p < 0.001$). More specifically, semiprofessionals differed from all the developmental groups (U10 $p = 0.007$, U12 and U14 $p < 0.001$). Amateurs differed from the U12 ($p = 0.003$) and U14 players ($p = 0.001$). Of the developmental groups, the lowest value was showed by U10, with the U12 and U14 having similar and high values, although these differences were not statistically significant ($p > 0.05$). The differences are presented in Figure 1.
In the fitness tests the groups of semiprofessionals and amateurs showed better performance than all the groups of developmental ages. In the 30 m sprint semiprofessionals were faster than amateurs ($p = 0.019$). In the same test the U10 and U12 did not differ statistically ($p = 0.092$), with the U12 being faster than the U10. The U14 were faster than the U12 and U10 ($p < 0.001$). The differences are given in Figure 3.
In the agility test the semiprofessionals were faster in the Illinois agility test than the amateurs ($F = 226.528$, $p < 0.001$), while in the T-test for the developmental ages the U14 players were faster than the U10 and U12 ($F = 35.965$, $p < 0.001$) without any other differences observed. The differences are presented in Figure 3.
As for the jumps in the CMJ that were common to all groups, the performance of adults differed with those of the developmental ages ($p<0.001$), but also between them ($p < 0.001$), with semiprofessionals showing a higher

Table 1. Confidence intervals

Variable	Amateur	Semiprofessional	U10	U12	U14
Age	20.6-25.7	21.8-24.3	9.1-9.7	10.7-11	12.8-13
Height	1.71-1.77	1.77-1.80	1.33-1.40	1.45-1.48	1.57-1.61
Weight	68.5-78	72.1-76	29.7-35.7	38.8-43.7	48.2-53.2
BMI	22.8-25.2	22.9-23.8	16.5-18.4	18.3-20	19.2-20.7
Body fat	13.3-17.7	11-12.5	14.6-20.7	18.8-23.4	19.2-23.3
30 m	4.34-4.49	4.13-4.23	5.68-6.03	5.41-5.77	5.07-5.25
LJ			144-158	146-160	167-178
SJ	28.3-30.2	34.8-36.2			
CMJ	28-32.1	34-37.2	17.5-22.5	17.7-20.6	19.6-21.5
T-test			13.41-14.24	13.11-14.11	11.70-12.09
Illinois test	17.49-18.19	15.36-15.61			
Sit and reach	22.11-27.11	26.72-30.22	12.98-20.60	12.81-16.90	10.58-15.03
YYIE1			767-1186	850-1177	836-1135
YYIR1	596-780	1013-1121			
Abdominals	27.4-33.5	27.3-28.9	18.5-21.8	18.6-22.2	21.5-24.7

U10 – under 10; U12 – under 12; U14 – under 14; BMI – body mass index; LJ – long jump; SJ – squat jump; CMJ – countermovement jump; YYIE1 – Yo-Yo intermittent endurance test level 1; YYIR1 – Yo-Yo intermittent recovery test level 1



* significant differences between adults (amateur, semiprofessional) and groups of developmental ages;
** significant differences between semiprofessional and amateur;
# significant differences between U14, U12 and U10 groups

Figure 3. Group performance at: A – 30 m linear sprint; B – T-test; C – Illinois agility test

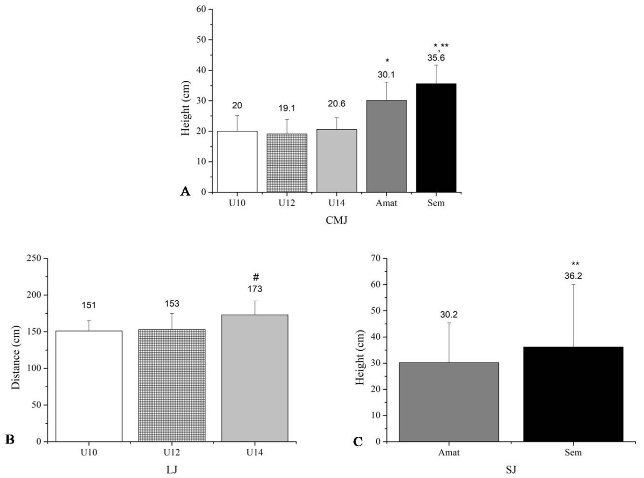
performance. No differences appeared between the U10, U12 and U14 groups (p>0.05). In SJ, semiprofessionals performed better than amateurs (F = 33.626, p < 0.001). In LJ, the U14 players performed better than the U10 and the U12 (F = 17.131, p < 0.001), while no other differences were recorded. The differences are presented in Figure 4.

In the sit and reach test, groups of adults differed from those of developmental ages, showing better performance (F = 38.234, p < 0.001). The worst performance was shown by the U14 players, but there are no statistical differences between the development groups. The differences are given in Figure 5.

In the endurance of the abdominal muscles differences were observed between the groups of adults (semiprofessional, amateur) and the groups of the developmental ages (F = 24.48, p < 0.001). The best performance was shown by semiprofessionals in adults and U14 in developmental ages. The differences are shown in Figure 5.

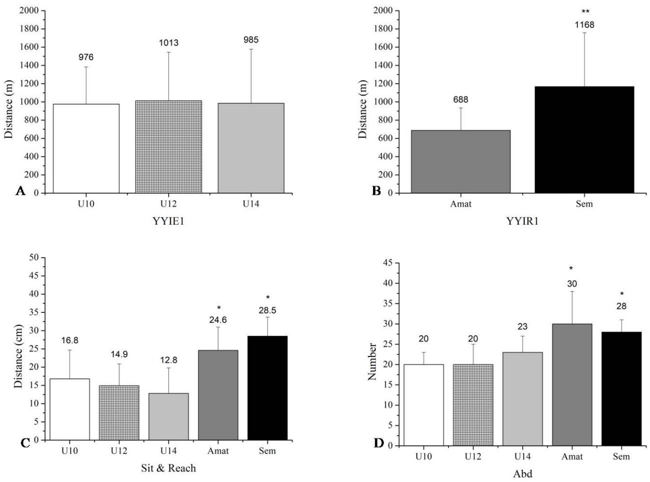
In the YYIR1 test semiprofessionals ran a longer distance than amateurs (F = 18.153, p < 0.001). In the YYIE1 test there were no differences between the groups of developmental ages (p = 0.958), with the U12 showing the best performance. The differences are presented in Figure 5.

The correlations between anthropometric characteristics and fitness tests are given in Table 2.



* significant differences between adults (amateur, semiprofessional) and groups of developmental ages;
** significant differences between semiprofessional and amateur;
\# significant differences between U14 and U12 and U10 groups

Figure 4. Group performance at: A – CMJ; B – LJ; C – SJ



* significant differences between adults (amateur, semiprofessional) and groups of developmental ages;
** significant differences between semiprofessional and amateur

Figure 5. Group performance at: A – YYIE1; B – YYIR1; C – sit and reach; D – Abdominal endurance test

Table 2. Correlations between variables

Group		Weigh	Height	BMI	BF	30 m	LJ/SJ	CMJ	T-test/ Illinois	S&R	Abd	YYIE/ YYIR
K10	Weight		r = 0.845 p < 0.001	r = 0.866 p < 0.001	r = 0.808 p < 0.001							
	Height			r = 0.469 p = 0.043	r = 0.676 p = 0.001							
	BMI				r = 0.675 p = 0.002							
	BF						r = –0.536 p = 0.022	r = –0.469 p = 0.043		r = –0.597 p = 0.009		
	30 m						r = –0.521 p = 0.022					
K12	Weight		r = 0.670 p < 0.001	r = 0.919 p < 0.001	r = 0.805 p < 0.001	r = 0.412 p = 0.007	r = –0.442 p = 0.002	r = –0.425 p = 0.004	r = 0.385 p < 0.009		r = –0.392 p < 0.029	
	Height			r = 0.331 p = 0.026	r = 0.310 p = 0.038							
	BMI				r = 0.863 p < 0.001	r = 0.353 p = 0.022	r = –0.531 p < 0.001	r = –0.370 p = 0.012	r = 0.316 p = 0.034		r = –0.383 p = 0.033	
	BF						r = –0.510 p < 0.001	r = –0.479 p = 0.001				
	30 m						r = –0.761 p < 0.001	r = –0.572 p < 0.001	r = 0.737 p < 0.001		r = –0.708 p < 0.001	
	LJ/SJ							r = 0.532 p < 0.001	r = –0.552 p < 0.001		r = 0.595 p < 0.001	
	T-test/ Illinois							r = –0.546 p < 0.001				
	Abd							r = 0.390 p = 0.03				
	YYIE/ YYIR							r = 0.359 p = 0.018				

K14	Weight	r = 0.686 p < 0.001	r = 0.873 p < 0.001	r = 0.541 p < 0.001			r = –0.270 p = 0.032		r = 0.350 p = 0.023	
	Height		r = 0.252 p = 0.046			r = 0.324 p = 0.01				
	BMI			r = 0.692 p < 0.001	r = 0.400 p = 0.001		r = –0.283 p = 0.025		r = 0.315 p = 0.042	
	BF				r = 0.607 p < 0.001	r = –0.335 p = 0.007	r = –0.312 p = 0.013			
	30 m					r = –0.500 p < 0.001	r = –0.487 p < 0.001	r = 0.392 p = 0.002		r = –0.370 p = 0.04
	LJ/SJ						r = 0.486 p < 0.001	r = –0.456 p < 0.001		r = 0.435 p = 0.014
	T-test/ Illinois						r = –0.325 p = 0.009			r = 0.401 p = 0.025
	YYIE/ YYIR			r = –0.338 p = 0.007	r = –0.271 p < 0.031			r = –0.438 p < 0.001		
Amateur	Weight	r = 0.771 p < 0.001	r = 0.890 p < 0.001	r = 0.540 p = 0.007						
	BMI	r = 0.404 p = 0.02		r = 0.606 p < 0.001					r = 0.433 p = 0.027	
	BF					r = –0.496 p = 0.005			r = 0.465 p = 0.022	
	30 m					r = –0.404 p = 0.016	r = –0.449 p = 0.007	r = 0.361 p = 0.033		
	LJ/SJ						r = 0.893 p < 0.001			r = 0.454 p = 0.001
	Abd						r = –0.352 p = 0.048	r = –0.490 p = 0.004		
	YYIE/ YYIR					r = 0.473 p = 0.008				
Semiprofessional	Weight	r = 0.682 p < 0.001	r = 0.739 p < 0.001	r = 0.430 p = 0.001				r = 0.266 p = 0.043		
	BMI			r = 0.447 p < 0.001			r = –0.350 p = 0.007	r = 0.298 p = 0.023		
	BF					r = –0.265 p = 0.043				
	LJ/SJ						r = 0.802 p < 0.001	r = –0.507 p < 0.001		
	T-test/ Illinois						r = –0.436 p = 0.001			
	YYIE/ YYIR				r = –0.338 p = 0.009			r = –0.318 p = 0.015		

BMI – body mass index; BF – body fat; LJ – long jump; SJ – squat jump; CMJ – countermovement jump; S&R – sit and reach test; Abd – abdominal test; YYIE – Yo-Yo intermittent endurance test level 1; YYIR – Yo-Yo intermittent recovery test level 1

Discussion

The main purpose of this study was to compare anthropometric characteristics and physical performance in players of four different age groups (U10, U12, U14, adults) and two different level groups (amateur, semiprofessionals). In addition, the existence of correlations between anthropometric characteristics and fitness tests was investigated. The results showed that anthropometric characteristics change with age, while semiprofessionals showed lower BMI and % body fat than amateurs. In fitness tests, adults performed better than players of the developmental ages. Between the two groups of adults, semiprofessionals performed better than amateurs. BMI and the percentage of body fat were correlated with many variables. It is noteworthy that none of the YY tests (for any age) were correlated with any anthropometric characteristic. With the exception of the U10 group, where the main correlation was between the two jump tests and between LJ and 30 m in all the other groups, there was a correlation between jump tests and agility test performance. Also, in the three groups (U12, U14, amateur) the performance in jump tests was correlated with the performance in the 30 m and abdominal tests.

The results showed that in the CMJ in the sit and reach test, the abdominal endurance test and the YYIE level 1 test there were no differences between the developmental groups. In CMJ the values were similar, which may be due to the limited training stimuli for vertical jumping ability at the developmental ages. It is known that the stretch-shortening cycle (SSC) plays a significant role in the CMJ [6]. However, in order to improve it, appropriate training stimuli (e.g. plyometric exercises) should be applied.

In the sit and reach test the U10 players performed best and the U14 participants performed the worst among the developmental groups. However, these differences were not statistically significant. The decrease in performance may be due to the increase in the height of the players (10 cm between U10 and U12, and 13 cm between U12 and U14), where the connective and muscle tissue has not had time to adapt to this development [19].

The abdominal endurance test showed no differences between the developmental age groups, with the U14 performing slightly better. The performance of these three groups coincides with the average performance of children of the same age in the general population [25].

In the YYIE level 1 test there was no statistically significant difference between the three groups of developing ages (U10, U12, U14). The performance of the U12 was slightly better than that of the other two groups. These findings are also confirmed by a previous study [21], where 11- and 12-year olds had an average performance of 1420 m, while 12- and 13-year olds had an average performance of 1407 m (similar distances).

In the 30 m sprints, in the LJ and in the T-test the performance of the U14 differed from that of the U10 and U12 players. More specifically, in all the three tests the increase in age was accompanied by an improvement in performance. These are three tests, where force/time is a key factor for performance. It is known that the force and speed is positively related to muscle mass, which increases with the growth and biological maturation of soccer players [11]. However, if we look at the average age of each group (U10: 9.4y, U12: 10.9y, U14: 12.9y) we find that U10 with U12 have a difference of about 1.5y, while U12 with U14 have a difference of 2y. This may have affected the results for these observations with significant differences appearing only in the U14 group.

Semiprofessionals performed better than amateurs in all the tests. The difference in the level justifies this difference. Training at the highest level is characterized by higher intensities, greater loads and are more specialized for the improvement of players.

From the correlations it is characteristic that the percentage of body fat is negatively related to LJ at the developmental ages and to SJ in adults. Also, in the U10 group the only correlation between fitness tests was observed between LJ and 30 m sprint. The CMJ was the fitness test that showed most relationships with anthropometric characteristics and other tests [16].

More specifically, only the semiprofessionals showed no correlation between a jump test and the 30 m sprints. However, previous studies reported a relationship between jump performance and maximum speed [2, 10, 16, 27]. During acceleration, which is the initial phase of the sprint, power (force in the unit of time) plays an important role [28].

The performance in the T-test in the developmental ages U12 and U14 was significantly correlated to the LJ and to the 30 m sprint, while the Illinois test with the performance in the 30 m in the amateurs and with the SJ in the semiprofessionals. Correlations between agility tests with speed and jumping tests were also reported in previous studies. More specifically, Michailidis et al. [16] reported correlations between performance at 30 m and performance in two different agility tests, while previously Vescovi and McGuigan [27] and Little and Williams [13] reported similar findings. The lack of a correlation between performance in the Illinois test and performance in the 30 m test in the semiprofessionals is in line with the findings of Chaouachi et al. [5] in high-level young players. These differences between the groups in the present study and between different studies are due to the influence of different age, experience and different design of the researches [4].

Flexibility was related in some groups (U10, U14, amateur) only with anthropometric characteristics such as weight, BMI and body fat percentage. The performance in strength endurance of the abdominal muscles was related to the performance in the jump tests (LJ and SJ) in the U12, U14 and amateur groups. Performance in the Yo-Yo test was positively related to performance in the CMJ in the U12 group. Amateurs' performance in the SJ was correlated negatively with performance in the 30 m test. Performance of SJ for U14 and semiprofessional players was negatively correlated with performance in the T-test and the Illinois test, respectively.

The present study has some limitations. More specifically, at the developmental ages the groups are two years apart; it is a better solution to have a one year interval to minimize the biological maturity differences. Also, at the developmental ages biological maturation, which we did not evaluate, plays a very important role in performance of athletes.

Conclusions

In conclusion, this study presents the physical condition profile of players in developmental ages (non-elite), amateurs and semiprofessionals. The improvement of performance depends on training, but also on biological maturation and development. The study performed at the beginning of the training year (pre-season), after ~8 weeks of summer holidays, also reflects the phenomenon of detraining on the subjects' performance [26]. In adults the different level of athletes is shown in all physical ability tests with semiprofessionals performing better. Greater specialization of training contents (increase in volume and intensity at the highest level) causes more effective adaptations in soccer players.

Conflict of Interests

The authors declare no conflict of interest.

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Use only standard abbreviations and symbols. The expansion of an abbreviation should precede its first use

Table 1. Descriptive statistics and comparative analysis of maximal oxygen uptake (VO_2max in $ml/kg \cdot min^{-1}$) between genotypes of the I/D *UCP2* gene polymorphism

UCP2	DD					ID					II				
Sex	*N*	$\bar{x}$	*SD*	*Min*	*Max*	*N*	$\bar{x}$	*SD*	*Min*	*Max*	*N*	$\bar{x}$	*SD*	*Min*	*Max*
F	42	45.65	*6.14*	32.30	59.00	36	45.66	*7.18*	30.60	59.80	7	45.07	*7.60*	35.00	54.80
M	72	54.01[a]	*6.20*	40.30	79.00	70	55.60	*7.32*	42.30	76.80	12	59.07[a]	*9.04*	49.70	74.90

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