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REVIEW ARTICLE

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Physiological predictors of distance runners' performance: a narrative review

GERASIMOS GRIVAS

Abstract
The main purpose of this article was to review and discuss the current literature on the following physiological parameters: maximal oxygen uptake (VO_2max), running economy (RE), running velocity at vVO_2max (vVO_2max), time limit at vVO_2max (tlimit), running velocity at lactate threshold (vLT) and maximal speed (Vmax) on running performance. Many coaches and trainers believed that athletes with higher VO_2max have better performance, but a lot of studies have shown that VO_2max is a poor predictor of endurance performance. Alternatively, RE, vVO_2max, tlimit, vLT and Vmax were shown to be superior predictors of distance running performance. Therefore, if researchers and coaches can improve the values of all five parameters, the calculations suggested that the runner would be able to complete a marathon in 1:57:58. In conclusion, this review provides some practical suggestions as how to improve the performance in distance runners.

KEYWORDS: physiological parameters, performance, distance runners.

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Introduction

Many physiological variables are associated with aerobic function and are used to determine running performance [9]. These are: maximal oxygen uptake (VO_2max), running economy (RE), running velocity at VO_2max (vVO_2max), time limit at vVO_2max (tlimit), running velocity at lactate threshold (vLT), and maximal speed (Vmax). The resulting question is which of these is the better predictor for performance in distance runners. It is very difficult to answer because studies use runners with different backgrounds and ability levels. It seems, however, that the most beneficial might be using the combination of several physiological factors to predict endurance performance in runners.

VO_2max is relatively homogeneous in elite runners, and within elite populations, race times were shown to have only a low to moderate correlation with VO_2max. For example, elite endurance athletes may have VO_2max values ranging between 70 and 85 ml·kg^{-1}·min^{-1} [47]. Alternatively, physiological parameters like RE, vVO_2max, tlimit, vLT, and Vmax were shown to be superior predictors of distance running performance [1, 12, 20, 38]. The purpose of the current article is to discuss the role of VO_2max, RE, vVO_2max, tlimit, vLT, and Vmax and the significance of their implementation into distance runners' training. If the coaches or athletes consider the relevance of other physiological factors they will be able to maximize the running performance.

Maximal oxygen uptake (VO_2max)

VO_2max was first described by Hill and Lupton [28]. Over the following decades, VO_2max was accepted as a measure of the functional capacity of the cardiovascular system [27, 31, 46], and is taken as a measure of cardiorespiratory fitness. Average values in elite men long-distance runners range from 75 to 85 ml·kg^{-1}·min^{-1},

and from 60 to 75 ml·kg^{-1}·min^{-1} in elite women long-distance runners [51, 54].
Paradoxically, there is a little relationship between VO_2max and race times among competitive long-distance runners [2]. A paradox is that a runner who improves VO_2max from 60 to 66 ml·kg^{-1}·min^{-1} can usually be assured of an approximate 10% improvement in performance, but a runner with a VO_2max of 66 ml·kg^{-1}·min^{-1} has no assurance that that is 10% better than a competitor with a VO_2max of 60 [2]. Studies have reported that VO_2max is a poor predictor of endurance performance when athletes of widely varying abilities are compared [34, 39, 41]. Legaz Arrese et al. [34] examined the relationship of VO_2max on performance in trained endurance runners. The results showed no relationship between changes in VO_2max and race performance. The study of Ramsbottom et al. [45] found that improvements in a 5 km trial were correlated with RE but not with VO_2max, while in the study by Paavolainen et al. [43] 5 km performance actually declined with improvements in VO_2max.

Training effects on VO_2max
Two of the most common endurance training strategies are interval training and continuous training methods [23]. The study of Pollock [44] has shown that improvement in VO_2max is directly related to intensity, duration, and frequency of training. The study by Helgerud et al. [27] revealed that the 15/15 (15-s intervals at 90-95% HRmax with 15 s of active resting periods) and the 4×4 min training (4×4-min interval training at 90-95% HRmax with 3 min of active resting periods at 70% HRmax between each interval) significantly increased the level of VO_2max in healthy students. However, long slow distance running (continuous run at 70% HRmax for 45 min) and lactate threshold running (continuous run at lactate threshold at 85% HRmax for 24.25 min) did not change their VO_2max. Another study [3] performed in young individuals with average cardiorespiratory fitness, shown that 20 sessions of periodized high volume interval training led to significant increases in VO_2max. Similarly, Gorostiaga et al. [24] when compared the effects of interval and continuous training programs on VO_2max showed that VO_2max was increased by 5% in the continuous training program, and 10% in the interval training program. The research clearly shows that continuous base training is an inefficient way to build an aerobic base and that the interval training improves VO_2max more effectively.

Running economy (RE)
Among the factors that may predict middle- and long-distance running performance, running economy (RE), commonly defined as the steady-state VO_2 required at a given submaximal speed, has gathered the most attention over the last decade, although it is often still referred to as “being relatively ignored in the scientific literature” [4]. In the last decades, the researchers have focused on measuring RE in distance runners and many studies have found a strong association between RE and race performance. Some studies indicate that RE is an even better predictor of race performance among elite runners than VO_2max [16, 39, 47, 48].
Runners with good RE use less oxygen to run at a specific velocity compared to runners with less optimal economy [2]. When comparing two runners with similar VO_2max values the runner with better RE will achieve better performance time. Kenyan and Ethiopian runners have dominated middle- and long-distance running events compared to European runners. The runners from Africa do not have a higher VO_2max compared to European runners, but they have better performance [58]. The explanation is that African runners are typically smaller even compared to other elite runners, and studies have shown that smaller runners and runners with thinner and shorter lower limbs have better RE [14].
RE is a strong predictor for performance [32] because a runner with a greater economy will tend to work at lower percentages of VO_2max for various speeds than a runner who requires more oxygen and therefore has a poor economy [2]. For example, if two runners in a race have the same pace but one runner’s oxygen-consumption rate is 80% of VO_2max while the second runner’s oxygen-consumption rate is 90% of VO_2max, the first runner will continue the race for a greater distance than the second one. More specifically the first runner has greater RE than the second.
Numerous studies have examined the effects of RE in distance runners’ performance and found a strong association between RE and race performance. More specifically, Di Prampero et al. [18] reported that a 5% increase of RE induced a 3.8% increase in distance running performance. Weston et al. [57] investigated the RE and 10 km performance in African and Caucasian distance runners. African and Caucasian runners had similar race times in 10 km, but the African runners had a 13% lower VO_2max, but 5% better RE than Caucasians. This study indicates a greater RE and higher fractional utilization of VO_2peak in African distance runners. The study of Conley and Krahenbuhl [15] determined the relationship between RE and distance running performance in highly trained and experienced distance runners. All runners had similar VO_2max and within this elite cluster of finishers, 65.4% of the variation

observed in race performance time on the 10 km run could be explained by variation in RE.

On the other hand, only a few studies suggested that RE was not associated with running performance in competitive distance runners. Mooses et al. [39] suggested that in the homogenous group of Kenyan distance runners, RE can be compensated for by other factors (such as VO_2max) to maintain high-performance levels. Similar results are found in the study of Grant et al. [25] who reported that neither VO_2max nor RE was strongly correlated with the performance of 3 km. They also reported that vLT plays an important role in a 3 km running performance.

A variety of training strategies have been adopted in an attempt to improve RE. The most common training factors for improving RE are strength training (plyometric), tapering, hill, and pace-specific training (Figure 1).

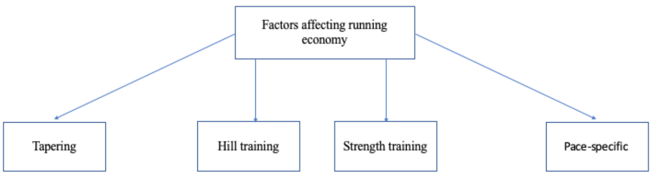

Figure 1. Training factors for improving running economy

Strength training

RE improvements, as a consequence of strength training interventions, have been attributed to improved lower limb coordination and muscle coactivation, which would ultimately increase muscle stiffness and decrease ground contact times [35]. A meta-analysis published by Balsalobre-Fernández et al. [4] examined the effects of strength training on RE in highly trained distance runners. Authors reported that a strength training program including low to high-intensity resistance exercises and plyometric exercises performed 2-3 times per week for 8-12 weeks was an appropriate strategy to improve RE in the highly trained middle- and long-distance runners. The study by Li et al. [35], demonstrated improvement in RE and performance of 5 km running after complex training, which included a back squat + a drop jump from a 40 cm box; a Bulgarian split squat + a single leg hop; and a Romanian deadlift + a double leg 50 cm hurdle hop. Similarly, the study by Støren et al. [55] reported that maximal strength training for 8 weeks improved RE by 5.0% among well trained, long-distance runners, without a change in maximal oxygen uptake or body weight. Sedano et al [50] indicated that 12 weeks of combined and plyometric training lead to improve RE. Paavolainen et al. [43] showed that 9 weeks of explosive-strength training improved RE (8%) and 5 km performance (3%) in moderately trained runners. The study by Saunders et al. [49] reported that in a group of highly-trained distance runners, 9 weeks of plyometric training improved RE by 4.1%, with likely mechanisms residing in the muscle, or alternatively by improving running mechanics. In a study of Blagrove et al. [13], ten weeks of strength training (2 days/week) added to the program of a postpubertal distance runner was highly likely to improve maximal speed and enhance RE by 3.2-3.7%. The study of Beattie et al. [7] demonstrated that 40 weeks of strength training can significantly improve maximal and reactive strength qualities, and RE by 5.0% in distance runners.

Tapering

Tapering is the reduction in training load before the competition or the final period before a major competition and it is very important for the athlete's performance. The aim of tapering is to maximize physiological adaptation with the reduction of accumulated fatigue [26]. Only 3 studies examined the effects of tapering on RE. The study of Houmard et al. [30] indicates that 7 days of tapered running improved distance running performance and RE by 6% in a group of well-trained endurance runners. In another study [52] RE at 60% vVO_2max was improved after 16 days of tapering. It is in agreement with the study of Houmard et al. [29] who investigated the effects of tapering on RE at 85% VO_2max speed after 2 and 3 weeks of taper and at 65% VO_2max after 3 weeks of taper.

Hill training

Hill training is another strategy that enhances RE. Only one study examined the effects of six-week hill training on RE in distance runners and showed its improvement by 2.4% ± 1.4% [5].

Pace-specific training

Tempo runs are believed to enhance RE at the chosen training speed. Indeed, the study of Paavolainen et al. [43] suggested that muscle power may influence RE both at submaximal velocities and most probably at race pace. However, the study of Beneke and Hütler [8] indicated that training tends to improve economy the most at specific speeds used during training. This has important implications for the overall construction of a training plan. Moreover, 5 km runners should include a significant amount of training at the goal 5 km pace in order to optimize the economy at their desired intensity, and marathoners should insert segments paced at their marathon goal speeds into their long runs and tempo runs [12].

Running velocity at VO_2max (vVO_2max)

vVO_2max it is the minimum running velocity that elicits a runner's maximal rate of oxygen consumption or VO_2max [2]. Some studies suggest that vVO_2max is the best predictor of running performance [17]. vVO_2max combines VO_2max and RE into a single factor and explains differences in performance that VO_2max or RE alone cannot [25]. The study of McLaughlin et al. [38] showed that among well-trained subjects − heterogeneous in VO_2max and running performance − vVO_2max is the best predictor of running performance because it integrates both maximal aerobic power and the RE. Morgan et al. [40] reported that there is a strong relationship between vVO_2max and 10 km run time. Data from this study also suggest that vVO_2max may be potentially useful as an index of training status and a sensitive, noninvasive predictor of distance running performance. McCormack et al. [37] reported that vVO_2max was the best predictor of 3 km race performance in a group of collegiate distance runners with heterogeneous VO_2max values. A study by Slattery et al. [53] showed similar results and explain that close relationship between vVO_2max and 3 km race time may be due to the fact that middle distance races are completed at a velocity similar to that of VO_2max, whereas velocities of longer distance races are closer to lactate threshold, and therefore vVO_2max may become a better predictor of performance in the middle-distance events.

On the other hand, Grant et al. [25] found that vVO_2max was the third-best predictor of 3 km run performance behind vLT and velocity at 4 mmol of blood lactate. According to Emerick et al. [19], this study failed to support the use of vVO_2max as the best predictor of marathon performance in a group of recreational female runners. The study reinforced the notion that VO_2max combined with weekly training distance elicits the best prediction of marathon performance. These findings suggest that recreational female runners should focus on increasing their VO_2max and increasing their total training distance to improve their marathon performance. Endurance runners, coaches, and exercise physiologists gained the notion of why vVO_2max is a much more useful performance predictor in distance running than VO_2max. The latter contains no information about an athlete's RE. In case of a runner with high VO_2max and low levels of RE, his performance could be disappointingly slow despite the high aerobic capacity [2].

Time limit at vVO_2max

The time limit at vVO_2max (tlimit) is also important for distance running performance and is a sister measurement of vVO_2max. To determine the time limit at vVO_2max the athlete runs at 100% of vVO_2max until exhaustion, without slowing the pace or stopping. Direct measurement of tlimit indicates that it ranges from 150 s to 10 min and cannot last longer than 20-25 min [11, 33]. Billat [10] showed that the time limit at vVO_2max was on average 6 min. Tlimit has a practical application in endurance athletes, for example, if two runners have similar values of vVO_2max, the runner with higher tlimit will win the race.

Running velocity at lactate threshold (vLT)

Determining lactate threshold (LT), defined as the point at which blood lactate concentration increases exponentially with increasing exercise intensity, has been used to ascertain endurance capability, measure adaptations to training, and to predict performance potential [22]. Furthermore, LT is considered a valid performance indicator as there are strong linear correlations with endurance performance [21].

Running velocity at lactate threshold (vLT) is simply the velocity above which lactate begins to accumulate in the blood. Like RE and vVO_2max, vLT is a strong physiological predictor of endurance performance [6]. Many coaches and researchers try to move the vLT to progressively faster speeds. Having a high vLT means that a runner can process pyruvate at greater rates and thus has the energy needed to run fast and long during endurance competitions [2].

In athletes with several years of training experience, VO_2max may not improve any more, but vLT might increase by 3-10% depending on the chosen training program. It has been observed that individuals with similar VO_2max have variability in endurance capacity and that highly trained athletes usually perform at a high percentage of their VO_2max with minimum lactate accumulation [56, 59]. Furthermore, trained athletes accumulate less lactate than untrained athletes at a given submaximal workload.

Maximal speed (Vmax)

The study by Noakes et al. [42] was the first to report that maximal speed was a strong determinant of endurance performance. This study showed that peak treadmill velocity was the best laboratory predictor of running performance at 10, 21.1, 42.2, and 90 km distances in ultra-marathon runners, and it was also the best predictor of running performance for 10 and

21.1 km distances in marathon runners. The results of the Slattery et al. [53] study, showed that Vmax was the single best predictor of 3-km running performance in experienced male triathletes and that both aerobic and anaerobic abilities are related to improved 3 km time trial performance. Since the assessment of Vmax is relatively simple to implement, we suggest that determining Vmax could be a practical method for monitoring performance changes in short-term endurance running events. The study of Paavolainen et al. [43] provides strong evidence that explosive training improves maximal running velocity and that the increases in maximal speed are closely coupled with improvements in endurance performance. This study examined 18 athletes who ran an all-out 20-meter sprint and a 5 km race (as fast as possible) on an indoor track. After 9 weeks the explosive-trained runners noted a 3% improvement and were 30 seconds faster in the 5 km event. Manoel et al. [36] compared the effects of 4 weeks of Vmax or vVO_2max training in endurance runners. The results showed a significant effect of training on Vmax and 10 km performance. It was concluded that Vmax training promoted similar improvements as the training that included vVO_2max.

Conclusion

Many coaches and trainers believed that athletes with higher VO_2max have better performance. Many recent studies have shown that VO_2max alone is rather a poor predictor of endurance performance. It seems that actually, besides VO_2max, the physiological factors that are associated with aerobic capacity are RE, vVO_2max, tlimit, vLT, and Vmax.

Conflicts of interest

The authors declare no conflict of interest.

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REVIEW ARTICLE

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Can non-conventional methods support recovery from exercise-induced muscle fatigue in people over 60 years old?

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Abstract
Physical effort contributes to improving the level of physical fitness and fatigue tolerance, however, may cause overtraining and/or chronic fatigue. Recovery is a regenerative process that takes place in every individual and is related to circadian rhythms. The aim of this review was to consider the factors and methods that determine and support the recovery from exercise-induced muscle fatigue especially in older people above 60 years of age. We have searched three online databases: Web of Science, PubMed, and Google Scholar. Based on our narrative review, there are few non-conventional methods (like mindfulness and meditations) that play an important role among numerous non-pharmacological therapies used to enhance or maintain the cognitive function of the body and mind. However, there is still a gap concerning the inclusion of mindfulness meditation as a part of recovery from exercise-induced muscle fatigue.

KEYWORDS: overtraining, recovery, meditations.

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Introduction

The physical effort of different intensities performed by people of all ages undoubtedly contributes to improving the level of physical fitness and fatigue tolerance, but above all, it is a manifestation of care for maintaining good health and functional fitness of older people. Based on statistics showing that the proportion of people over 65 years of age by 2035 will increase by around 10%, this aspect of an active lifestyle is a factor in mitigating the effects of aging. Thus, the maintenance of good health and functional capacity of the elderly reduces the social costs of treatment and rehabilitation of chronically ill patients [11, 62]. The effectiveness and the organism's response to the applied exercise load depend on certain factors. On the one hand, they are directly related to the health status or level of physical fitness, but also to the atmospheric conditions in which exercises are performed or eating habits and behaviors. The disturbances of the internal organism's homeostasis resulting from the exercise stimulus are the cause of the formation of numerous morphofunctional adaptations and an increase in one's exercise capacity. The body's natural reaction to the physical effort is the appearance of fatigue, which protect the body from excessive overload and exhaustion. The strength generated by working muscles is reduced, thus decreasing the effectiveness of work. Despite the development of fatigue, it is possible to continue the effort but to maintain the generated strength additional muscles are engaged, which significantly increases the energy cost of the effort. Physiological mechanisms underlying fatigue concern functional changes within the skeletal muscle itself, structures supplying it with oxygen, metabolic energy sources, but also in the nervous system structures performing coordinating functions and generating electrical impulses. The impact on each of these elements depends on the type of effort, intensity, age, and gender of the exercising person. Peripheral muscle changes occurring during the exercise of different duration are usually accompanied by central changes located in the nervous system. Peripheral fatigue is caused by the impairment of cell stimulation mechanisms and/or nerve-muscle synapse. It also leads to impairment of electromechanical coupling mechanisms, a decrease in the concentration of energy substrates, decomposition of the contractile apparatus, and damage to the connective tissue of ligaments and tendons. Increased concentrations of adenosinodiphosphate (ADP), inorganic phosphate (P), and hydrogen ions (H^+) are caused by the restriction of oxygen access to working muscles and increased glycolytic metabolism. Additionally, the cardiovascular and respiratory systems are overloaded. The formation of lymphatic edema in working limbs and a decrease in adrenal catecholamine secretion can be observed [60]. During short-term work of high intensity, the occurrence of fatigue changes is additionally caused by slowing down the transmission of the pulse in the nervous system and an increase in the concentration of ammonia from the purine transformations in the cell. This compound increases the activity of glycolytic enzymes, and in the nervous system, it additionally impairs the transmission of stimuli. Studies have shown that elderly people are more resistant to fatigue changes. This is probably due to the disappearance of FT II fibers with age and a higher proportion of oxidative FT I fibers [16, 21]. Tarnopolsky et al. [57] demonstrated that lower muscle glycolytic capacity and more effective lipid metabolism are the factors determining their higher resistance to fatigue in women of all ages. In the study on the rate of muscle regeneration after exercise in people of different ages and genders, Grounds [14] described an age-dependent decrease in the possibility of rapid post-exercise regeneration. He also found, that in the elderly, the long-lasting occurrence of fatigue symptoms led to balance impairments, which increased the risk of their falls.

To cause adaptive changes effective training must be associated with overload and at the same time disproportions between training and regeneration time should be avoided. Lack of sufficient period of recovery in the training process leads to the accumulation of fatigue changes and the development of overtraining. Factors such as cardiopulmonary efficiency, the composition of muscle fibers, hypoxia of working muscles, dehydration, and electrolyte disturbances affect the time of appearance, and persistence of overload changes [29]. The most susceptible to physiological and anatomical overload changes are endurance athletes, young people, and those over 40 years of age. Moreover, women overtrain faster than men [16]. Thus, the coaches should be expected to have an appropriate level of empathy towards over-trained individuals [16, 21].

The consequences of overtraining are common and include numerous physiological pathways, including neuroendocrine, immune, cardiovascular, and musculoskeletal paths. Negative nitrogen balance and amino acid imbalances lead to an increase in blood levels of free tryptophan. It reaches the brain and become a precursor of serotonin neurotransmitter. Increased serotonin concentration is manifested by mood swings, changes in behavior and inhibits motoneuron excitation. This affects the nervous and hormonal regulation in overload conditions [28, 37, 42].

Clinical features of overtraining in different individuals are varied and non-specific. They depend on the specifics of the exercise. The features such as a decrease in the level of physical fitness, fast fatigue during training sessions, anxiety, and decreased body immunity are common to both types of overtraining [30]. In young athletes especially training endurance and speed/power sports, the observed changes are caused by excessive stimulation of the sympathetic nervous system. Sleep disorders, and weight loss, are accompanied by cardiac changes like increased level of resting heart rate (HR) and blood pressure (BP) with simultaneous disruption of orthostatic reactions. In endurance sports, especially in those with a high level of cardiopulmonary and respiratory efficiency and long training experience, the disorders stimulated by the parasympathetic nervous system dominate in the overtraining process. They do not lose weight, their sleep is calm, their resting HR and BP are decreased. Hypoglycemia is a frequent post-workout metabolic disorder. This type of overtraining is difficult to diagnose and treatment lasts even several months. No single test is diagnostic in the assessment of the type and severity of occurring overtraining. The best way of treatment and prevention is prophylaxis, i.e. optimization of the training process and regeneration of the body. From a health-related point of view observation and diagnosis of mood changes, sleep disorders, monitoring the level of physical fitness, stress reduction, and dietary guidance will ensure that the beneficial effects of physical activity are obtained [15, 58].

Conventional recovery

The subject of recovery has been a topic of discussion for years since it accompanies each individual every day. Recovery is a regenerative process, that is related to circadian rhythms. Biological renewal, both daily and during physical activity, can be supported by a number of conventional and non-conventional measures to optimize physiological rest processes, protect health and maintain or increase the psychophysical capacity of an individual engaged in physical activity, both amateurs, and professionals.

Recovery is defined as the process of restoring the ability to exercise efficiently or the process of restoring homeostasis through the normalization of physiological functions. An important aspect of the analysis of rest after the physical and mental activity is paying attention to the role of the autonomic system. The activity of the sympathetic nervous system prevails during exercise, while the parasympathetic system is at rest [52]. After the physical or mental activity, the nervous system should rest and regenerate. The exhausted sympathetic nervous system manifests by the reduced ability to undertake or maintain effort [3]. Rest aims to balance homeostasis after exercise or taking actions supporting the regenerative process, also by undertaking other efforts called active rest. Post-exercise restitution may take minutes, hours, or days, depending on the intensity and volume of the bout. We should also remember that each individual has its resistance to fatigue and regenerative predisposition. The effectiveness of post-exercise restitution will therefore also depend on the lifestyle of the person undertaking the exercise [52].

Bearing in mind the healthy lifestyle, which correlates with post-exercise restitution, attention should be paid to the following factors:

1. Constant hours of sleep and waking up. Both too short and excessively prolonged sleep may result in the occurrence of many health disorders related to metabolic, depressive, or vascular causes. An appropriate time of sleep (7-8 hours) allows the body to rest and is appropriate to maintain the energy necessary to conduct regular physical activity [11, 26, 27].
2. Healthy nutrition. For the psychophysical well-being, and in particular, with an active lifestyle, a properly composed diet seems an important factor that can provide energy and nutrients based on the guidelines of the newest pyramid of healthy nutrition and physical activity adjusted to age. Fixed eating times are important, therefore, 5 meals a day eaten every 2-3 hours are preferred [18]. Vitamin and mineral supplementation should be considered in some people, while in the elderly, vitamin D_3 supplementation is necessary [13, 35, 62]. The researches confirm that planned nutrition can have a significant impact on sports performance [64].
3. Adequate hydration of the body. Within 24 hours the body should be supplemented with about 40 g of water per 1 kg of body weight [9, 17, 23, 46]. The amount of drunk fluid should depend on the weather conditions, the mode, intensity, and duration of performed exercise. Modern recommendations for drinking water during physical activity are based on starting activity while hydrated, preventing dehydration during ongoing training, and replacing lost fluids after training [2, 36, 44].
4. The ability to cope with the stress of everyday life. Learning the ability to introduce one's body into a state of relaxation, i.e. a pleasant short-term rest, which is experienced as internal relaxation, peace, and carefree [32, 62]. Preferred relaxation techniques are autogenic training, Jacobson's relaxation, or exercises for controlled diaphragmatic breathing [49].
5. Regular physical activity. WHO recommends moderate physical activity for min. 150 minutes (2 hours 30 minutes) a week, at best divided into 30-minute single bouts, performed minimum five times a week. The importance of 30-45 minutes of physical effort is increasingly emphasized. The physical efforts should affect coordination, balance, strength, and include aerobic exercises with an intensity of 60-80% of the predicted maximum heart rate and stretching elements [51].

All the mentioned components of a healthy lifestyle will allow the body to recover faster after exercise. In addition, after physical exercise of a sports nature, it is recommended to perform short light stretching and relaxing exercises and the use of thermotherapy treatments and massage, which accelerate the removal of waste products from the body [52].

One of the modern forms of self-massage, Foam Rolling (using a massage roller), is one of the most effective and simple methods of relaxing the excessively tensed muscular apparatus after training. Used after training, it regenerates, relaxes, and relieves pain from tired muscles [4, 40, 47, 48].

The recommended thermotherapy treatments concern hot or cold treatments. Hydrotherapeutic treatments can be divided into groups concerning induced pressure: hydrostatic (baths), hydrodynamic (showers), or without water pressure (saunas). During recovery the most commonly used water is cold (18-24°C) or cool (25--32°C), which promotes narrowing the blood vessels, increasing the blood pressure, slowing down the heart rate, stimulating the nervous system, reducing sweat secretion, and increasing muscle tension [45, 54]. Neutral (33-36°C) temperatures reduce muscle tension, enhances relaxation, and sleep quality [45]. The warm (37-38°C) and very warm (39-40°C) treatments are known of increasing blood supply to the skin, lowering blood pressure, accelerating heart activity, stimulating the autonomic nervous system, increasing sweat secretion, relaxing skeletal and smooth muscles, and are also characterized by analgesic, anti-inflammatory and relaxing properties [20, 25, 43, 54, 65].

Individuals that engage in systematic physical exercise are recommended to relax the myofascial tension and improve circulation. One of the possibilities is to take post-exercise contrast showers. The procedure begins with warm water for a few minutes (3-5 minutes) later alternated with several seconds (10-15 seconds) of cold water, ending always in cold water [6].

Another form of effective thermotherapy is a traditional sauna used either as a warm-up or as a regenerating treatment. A sauna bath supports the immunity of the body and accelerates regeneration [41]. However, it should be remembered that as a very stimulus procedure, it can be highly stressful to the body. Some studies even show that the heart effort during sauna treatments can be compared with a single bout of low-intensity exercise [31]. It should be emphasized that "sauna is a specific combination of overheating the body using hot, dry air with periodic, short exposure to high humidity and high electric field intensity, followed by cooling the body with an air bath and cold hydrotherapy treatments (e.g. cold a shower or a cold immersion bath for several seconds)" [53].

Another type of thermotherapy treatment that can complement the recovery process is the infrared sauna. It is much gentler in operation than a traditional sauna, as it has a temperature of 40-50°C and no steam component. This sauna is a great replacement for a traditional sauna and can be used by people with vascular and circulatory sensitivity. It can be used both before a single bout as a form of warm-up and/or after exercise, excluding excessive stress on the cardiac system [41].

Very natural recovery treatment is climatotherapy together with the air and sunbathing treatment included in its scope. Air baths build immunity and seem an appropriate environment for regular physical activity. Heliotherapy (treatment with the sunlight) with a relaxing effect on the body improves mood, but associated with such treatment UVB radiation is involved in the natural synthesis of vitamin D_3 in the skin of a person exposed to this wavelength of the ultraviolet spectrum [24, 60].

Local cryotherapy or warm compresses are other types of treatments with a specific anti-traumatic effect, used successfully by individuals practicing sports. They include gel packs (hot/cold packs). Local muscle cooling before or after exercise can cool down the body structure under heat stress and contribute to increased activation and regeneration of muscle strength. Warm gel packs allow relaxing tensed muscles. It should be remembered that we only use warm compresses on the area free from inflammation. In places, with overload, swelling, heat, redness, and pain we use only cold treatments [19].

Summarizing, it should be remembered that the body recovery process is self-limiting and largely dependent on lifestyle. By introducing biological recovery measures in the form of selected physical treatments e.g. thermotherapy, hydrotherapy, phototherapy, and massage, we act for anti-trauma prevention, supporting the natural process of recovery.

Non-conventional methods

Recovery is associated with better post-workout regeneration of fatigued muscles, tendons, and bones but also with the improvement of processes such as sleep. Sleep quality and post-sleep state is a high priority in quality of life. Insomnia is a relatively frequent sleep disturbance, being more prevalent among women since 40-55% of middle-aged women may show sleep disturbance [7, 38]. It might be caused by excessive stress, overwork, overstrain, or delayed onset muscle soreness (DOMS) felt in muscles several hours strenuous exercise. The phenotypic effect of insomnia might be seen among others in disadvantageous brainwave entrainment. Thus, it seems interesting to focus and recommend such procedures that enhance, among others, the process of falling asleep and sleep it-self. This aspect especially concerns people above 60 years of age. It is now considered whether meditation (a form of disconnection of active consciousness), usually used to and enhance muscle relaxation, can improve sleep quality [12].

Analysis of subjective ratings of sleep and awakening quality derived from the questionnaire of sleep and awakening quality [50], shows that quality of sleep can be significantly improved. Electroencephalographic studies on meditation have shown an overall electroencephalogram slowing (i.e., increased theta and alpha activity) [5]. Thus, meditation may be helpful for individuals who suffer difficulties with switching off the mind when attempting to sleep [39]. However, the large variety of used techniques and the variety of meditator's skills are potential biases [8]. It is assumed that better sleep quality and better muscle relaxation during and after meditation are associated with better recovery from exercise-induced muscle fatigue, which is slower in older people [55, 34]. There are some drugs − as resveratrol − used to enhance muscle fatigue resistance [1], yet, in this article, we have focused on non-pharmacological treatments.

Non-conventional methods that might support the recovery of exercise-induced muscle fatigue include mind-body interventions affecting bodily functions and symptoms including biofeedback, yoga, Taijiquan, hypnosis, guided imagery, praying, relaxation, and meditation [33]. In classical paper concerning the neuroscience of mindfulness meditation by Tang, Hölzel, and Posner in Nature Reviews Neuroscience meditation is defined as a "form of mental training that aims to improve an individual's core psychological capacities, such as attentional and emotional self-regulation" [56]. Authors emphasize that meditation encompasses a family of complex practices that include mindfulness meditation, mantra meditation, yoga, Taijiquan, and qigong. Given the body kinesthetic criteria, meditation practice (MP) can drop to one of three main subclasses. In the sitting position (zen, yoga, Buddhism), in the lying position (yoga, vipassana, Ma Yuan), or when the movement is involved (circle dances, Taijiquan, whirling dances, yoga, qigong, sustained exercise).

Research on meditation is still at the starting point and searching the Pubmed database using the phrase 'meditation' shows for the last 10 years merely 7,721 records and no more than 2,800 records for the last 5 years. However, the number of results of searching 'meditation' in the Google Scholar database increased from 38,000 in the years 1980-1990 to 213,000 records in the period 2010-2020. This data indicates that the interest in researching meditation is relatively average, but shows an upward trend.

Most meditation techniques are described in detail in numerous scientific articles. However, among the group of visualization techniques, Ma Yuan meditation is quite an unknown complex visual imagery technique. Ma Yuan (1160-1225) was a Chinese painter of the Song dynasty specializing in paintings of sea and lake waves (Figures 1, 2).

Figure 1. Ma Yuan painting of calm water surface, Wikimedia Commons

Figure 2. Ma Yuan painting of restless water surface, Wikimedia Commons

Ma Yuan meditation technique is a dynamic visualization of wave movements on the water surface in various weather conditions from smooth and calm to aggressive and sharp. These pictures are "only" the starting point to achieve a dynamic form of waving water surface and flowing across. Although this form of painting was very popular in China, only Ma Yuan paintings became an inspiration for meditators. However, it is unknown who was the real author of this meditation technique, yet, it might be assumed that it was the indigenous collective author of Chinese origin.

This meditation is based on anchoring/focusing the attention on the kinesthetic active picture of moving waves and thus switching off/disconnecting the active consciousness. Diving in this space of consciousness helps to distance from competitions and thus calming the emotions. Therefore, it seems important to search for optimal methods that would help to find a balance between appropriate stimulation and silencing. However, according to our best knowledge, there is no evidence concerning the influence of the Ma Yuan meditation technique for recovery and human wellbeing thus making it much more mystery than other well-known meditation practices.

In summary, there is no unequivocal evidence than non-pharmacological treatments enhance recovery from exercise-induced muscle fatigue, yet it is highly possible and therefore should awake our interest and evoke future complex research.

Conflicts of interest

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

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Are the field tests related to the match running distance and the technical performance in young soccer players?

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Abstract

Introduction. **A lot of studies have demonstrated the relationships between filed tests and match running performance in soccer players, but the impact of anthropometric characteristics and physical performance on technical abilities remains unclear.** Aim of Study. **The aim of this study was to examine the influence of physical performance on the technical abilities and match running performance of 20 young soccer players (U15) during soccer games.** Material and Methods. **Anthropometric profile, sexual-maturity assessment and physical performance tests (sprint tests, countermovement jump, squat jump, standing-long jump, multiple 5-bound test, sit & reach test, change of direction, and Yo-Yo intermittent endurance test level 1 – IE1) were conducted 3 weeks before the first of 10 soccer matches. Technical performance was determined by the frequency of actions during the 10 soccer games. Distance covered during matches was recorded using GPS devices.** Results. **The distance covered at speeds of 15.8-19.7 km/h correlated with performance in the long jump and Yo-Yo test (r = 0.49, P = 0.034, and r = 0.59, P = 0.008, respectively). The distance covered at higher speeds (19.8-24 km/h) correlated with performance in squat jump test and Yo-Yo test (r = 0.49, P = 0.032, and r = 0.50, P = 0.030, respectively). Factor analysis identified three technical actions of the highest importance: total activity, possession game, and attempts for goal. Multivariate canonical correlation analysis, used to verify the prediction of a multiple dependent variable set from field tests, showed that our model was not well adjusted.** Conclusions. **The current data suggest that the selected set of independent variables might not be useful in predicting technical performance in young soccer players. When we have the opportunity to select a young soccer player we have to use many fitness, technique, tactical and psychomotor tests to evaluate him. However, the Yo-Yo IE1 test was correlated to match running performance so it can be used by the trainers to predict match running performance of their young players.**

KEYWORDS: soccer, running performance, anthropometry, technical actions.

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Introduction

Soccer is an intermittent-type of sport that incorporates actions with low and high intensity and duration. Mohr, Krustrup, and Bangsbo [18] mentioned that in a soccer match, elite players cover a total distance of 9-12 km. Moreover, a player can perform more than 1350 intense activities during a match [18]. Aerobic and anaerobic capacities are therefore crucial for the actions of a soccer player, who wants to be successful.

Soccer performance depends on technical and tactical skills, though it is frequently used as a criterion for talent identification [16]. Many researchers have mentioned that players who managed to play at the elite level were more technically competent [8] and teams who longer maintained possession of the ball were more likely to be successful [15]. Some of these technical and tactical skills are the following: first touch, one-versus-one ability, striking the ball, and technique under pressure [16]. Soccer performance, besides mentioned physiological, technical, and tactical qualities, is in all age categories associated with psychological and sociological influences [9].
Valid information about a player's capacity can be obtained by applying objective and qualified tests. Many teams prefer field tests (like Yo-Yo) because they are easy to perform, they do not need expensive equipment and specialized staff to execute and are considered as a sustainable alternative for laboratory tests [13, 21]. The evolution of technology allows trainers to measure the distances covered by the players at different intensities during a match [1].
Numerous studies have demonstrated the relationships between filed tests and match running performance in soccer players [3, 4, 23]. In particular, Bradley and Noakes [3] mentioned positive correlations between the performance in the Yo-Yo intermittent endurance test 2 (IE2) test and the match running performance. These studies observed that the Yo-Yo IE2 test is not only related to match performances but can also differentiate between dissimilar intensities [3]. Similar correlations between distances covered at high intensity running and the Yo-Yo intermittent recovery test level 1 were reported by several researchers [4, 23]. Other factors that are correlated with the match running performance are the change of direction (Zig-Zag test), the peak running speed in a field test, and the mean sprint time in repeated anaerobic sprint test (RAST) [21, 23].
The researchers tried to find correlations between physical fitness tests (like Yo-Yo) and match running performance because that may help the trainers estimate their players' match running performance in an easy and fast way. Additionally, when repeated, this test could be used to assess the changes induced by training programs. Furthermore, finding field test correlating to match running performance would be of interest for soccer coaches as a tool for monitoring the players' progress and possible talent identification.
A few studies have mentioned the correlation of fitness filed tests with technical performance in specific technical tests [2, 11]. In a recent study, the influence of physical factors (hormonal status, sexual maturity, anthropometric profile, and physical performance) on the technical performance of young soccer players during small-sided games was examined [20]. The researchers found that the testosterone level was the most affecting factor for technical performance.
Because there is a particular need to find the universal fitness filed test correlating with match running and technical performance the aim of this study was to examine how the physical performance features (obtained with field tests) relate to match running performance and the technical abilities (obtained during 10 soccer games) in 20 young soccer players. Furthermore, we investigated whether the performance in field tests can explain the running and the technical performance during actual matches. It was hypothesized that a higher level of physical performance would be related to a better match running and technical performance.

Material and Methods

Subjects

Twenty young soccer players (U15) from a local soccer academy participated in this study. These players were field players who were in the starting squad and who were playing a full match. 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) not to be early and late pubertals, 3) having participated in ≥95% of training sessions of the year, and 4) not to be taking any medication. All participants and their parents were informed about the potential risks and benefits of the study and a consent form was signed by their parents. The local Institutional Review Board approved the study, in the spirit of the Helsinki Declaration. Participants' characteristics are shown in Table 1.

Table 1. Participants' characteristics (mean ± SD)

Participants (n = 20)	Mean ± SD
Age (y)	14.7 ± 0.5
Height (cm)	172.2 ± 7.3
Weight (kg)	62.4 ± 7.5
BMI	21.0 ± 1.9
%BF	16.2 ± 2.4

Note: %BF – percentage of body fat, BMI – body mass index

Body mass was measured to the nearest 0.1 kg using an electronic digital scale with the participants in their underclothes and 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 skinfolds (biceps, triceps, suprailiac, subscapular). Skinfold thickness was measured with a specific caliper (Lafayette, Ins. Co., Indiana) on the right side of the body as previously described [29]. The estimation of body density was calculated according to the Durning and Rahaman [6] equation for males under the age of 16 and estimated by the equation of Siri [28]. The chronological age at peak height velocity (PHV) of the players was estimated using the equation proposed by Moore et al. [19]. Early, average and the late matures were defined as those players with an estimated chronological age at PHV of less than 13 years of age, 13-15 years of age, and over the age of 15, respectively [26].

Methods

Fitness assessment (countermovement jump [CMJ], squat jump [SJ], long jump [LJ], multiple 5-bound test [M5B], speed [10 m & 30 m runs], change of direction [T-test], Yo-Yo intermittent endurance test level 1 [YY IET1]) were the independent variables of the study. The match running distance and the technical performance features were the dependent variables. The study was conducted during the beginning of the in-season period for 13 weeks. Particularly, the first 3 weeks were at the end of the pre-season period. The first week was the participant's familiarization with the field tests to minimize the learning effect error. During the second and third weeks, the appropriate field tests were performed. Later in the following 10 weeks, the players participated in 10 actual matches (in season). The tests were conducted 48 hours after any last training session. 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 10 weeks of the matches, all the participants competed in 10 matches and participated in 4 training sessions per week. The training session included soccer technical skills, tactics, speed and sprint workloads, and small-sided games. The total sessions' duration was approximately 90 minutes. All training sessions and matches were performed on a synthetic grass soccer field. The participants consumed water ad libitum to ensure proper hydration during training and testing and they did not intake any nutritional supplements or the ergogenic aids.

Speed testing

A 30-m sprint test with 10-m splits (0-10 m was measured as well) was used to measure speed performance. Sprint testing was performed with the participants wearing soccer shoes on a synthetic grass soccer field. After a 5-second countdown, the participants ran in front of 3 infrared photoelectric gates (Microgate, Bolzano, Italy) that recorded their time 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 limb motion. The coefficient of variation for test-retest trials was 3.4% [17].

Standing long jump test

The participants began the test with 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 of their legs and hands and then jumped horizontally as far as possible [14]. The horizontal distance between the starting line and the heel of the rear foot was recorded with a tape measure. The coefficient of variation fortest-retest trials was 2.5%.

Multiple 5-bound test

The participants, from a standing position, attempted to cover the longest possible distance with 5 forward jumps and alternating left and right leg contacts [17]. This test is considered to be a soccer-specific test, and it has been recommended for the measurement of lower limb muscle power and coordination instead of the vertical jump (VJ) test [5]. The maximal distance covered was recorded to the nearest 0.5 cm with a tape measure. The coefficient of variation for test-retest trials was 3.1%.

Vertical jump test

The participants performed two jump tests: (a) squat jump: participants, from a stationary semi-squatted position (90° angle at the knees) performed a maximal VJ, and (b) countermovement jump: 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 tests were performed with the arms akimbo. The VJ height was measured with Myotest equipment (Myotest, Switzerland). The coefficients of variation for test-retest trials were 2.8% and 3.8% in SJ and CMJ, respectively.

Change of direction test

The participants performed the T-test: subjects began with both feet behind the starting point A. At their discretion, each subject sprinted forward 9.14 m to point B and touched the base of a cone with the right hand. Then, they shuffled 4.57 m to the left and touched the base of a cone (C) with their left hand. Subjects then shuffled 9.14 m to the right and touched the base of a cone (D) with their right hand. Afterward, they shuffled 4.57 m to the left back to point B and touched the base of the cone with their left hand. Finally, subjects ran backward, passing the finish line at point A. An infrared photoelectric gate (Microgate, Bolzano, Italy) was placed at point A and recorded the time of each attempt [25].

Yo-Yo intermittend endurance test level 1

The Yo-Yo intermittend endurance test level 1 consists of repeated 20-m runs back and forth between the starting, turning, and finish lines at a progressively increased speed, which is controlled by audio beeps from a CD-player. When the subject failed twice to reach the finish line in time, the athlete stopped the test and the distance covered was recorded as the test result.

Video analysis

Video recordings of the soccer match were collected using a fixed camera (Sony, Brazil, 60 Hz frequency acquisition). The camera was located 10 m above and to one side long axis of the pitch. The Sport scout software was used for video analysis. The study was based on the two researcher's observations according to Singer and Willimczik [27]. Every match has been analyzed by two experienced observers who were specially trained for accurate and reliable data recording [27]. The kappa values for the analyzed variables ranged from 0.92 to 0.98 (intra-observer) and 0.85 to 0.95 (inter-observer). The applied technical actions have been described in a previous study [20].

Global Positioning System (GPS) analysis

To measure match performance, players wore 15-Hz GPS units (LAGALACOLLI Sport, Roma, Italy) positioned on the upper torso through a vest garment to reduce movement artifacts [10]. Units were activated according to the manufacturer's guidelines immediately before the pre-match warm-up. Players wore the same GPS device for each match to avoid any existing interunit variation. Afterward, the match data were analyzed and 6 speed indices for each half and the total match were used (0.1-5.99 km/h – walking, 6-11.9 km/h – jogging, 12-15.7 km/h – running, 15.8-19.6 km/h – high intensity running, 19.7-23.7 km/h – fast running, 23.8+ km/h – sprint).

Statistical analysis

All the statistical analyses were conducted using SPSS (version 24.0; SPSS Inc., Chicago, IL, USA) and the results are reported as mean ± SD. Shapiro–Wilks test was used to ascertain the normal distribution of the sample. Initially, factor analysis was used to identify the structure of relationships among the technical performance measurements to examine whether it would be possible to reduce the number of variables without compromising information. The most representative variables could be used in the subsequent canonical analysis. This analysis was used to examine the prediction of multiple dependent variables (the most representative technical performance measurements extracted from the factor analysis) from multiple independent variables (physical performance). Finally, Pearson's correlation method was used to examine the relationship between physical and technical performance tests with the match running performance. The level of significance was set at $P < 0.05$.

Results

Descriptive statistics (mean ± SD) of the field tests and the match running performance are presented in Table 2.

Table 2. Descriptive statistics of the field tests and the match running performance in young soccer players

Variables	Mean ± SD
Sprint 10 m (s)	1.95 ± 0.12
Sprint 30 m (s)	4.67 ± 0.27
CMJ (cm)	27.8 ± 4.3
SJ (cm)	27.1 ± 5.3
LJ (cm)	209.3 ± 19.2
M5B (m)	10.70 ± 0.97
Sit & reach test (cm)	28.1 ± 8.2
Yo-Yo IE1 test (m)	1031 ± 418
Match running performance	
Match TD (m)	7219 ± 682
Distance (0-5.99 km/h) (m)	2907 ± 297
Distance (6-11.8 km/h) (m)	2311 ± 602
Distance (11.9-15.7 km/h) (m)	1476 ± 322
Distance (15.8-19.7 km/h) (m)	547 ± 140
Distance (19.8-24 km/h) (m)	235 ± 86
Distance (>24 km/h) (m)	58 ± 58

Note: CMJ – countermovement jump, SJ – squat jump, LJ – standing long jump, M5B – multiple 5-bound test, Yo-Yo IE1 test – Yo-Yo intermittent endurance test level 1, TD – total distance

The results of the Yo-Yo IET1 and long jump were correlated with the distance covered at a speed of 15.8--19.7 km/h (r = 0.49, P = 0.034, and 0.59, P = 0.008, respectively). The distance covered in higher velocity (19.8-24 km/h) was correlated with the Yo-Yo IET1 (r = 0.50, P = 0.03) and SJ (r = 0.49, P = 0.032). No significant correlations were found between the other field tests and other variables of the match running performance.

As shown in Table 3, the factor analysis showed that three factors explain 92% of the total variance: 1st total activity 45%, 2nd ball possession (keeping the ball in teams' possession using passes) 30%, and 3rd attempts for goal 17%.

Table 3. Results of factor analysis with factor loadings

	Factor 1	Factor 2	Factor 3
Variable	total activity	ball possession	attempts for goal
Successful passes	–0.262	0.851	0.444
Headers	0.775	0.228	0.366
Complete tackles	0.910	0.249	–0.240
Goal attempts	–0.172	–0.552	0.784
Touches with the ball	0.902	0.206	0.199
Total distance	0.594	–0.778	0.012

The relation of the above three factors with the field tests was examined with the use of multivariate canonical correlation analysis. The variables with higher loading of each factor were retained for analysis. However, the adjustment of our data to the statistical model was not evidently good.

Discussion

This is the first study that simultaneously tests the correlation between field tests and technical and running performance during actual matches. The findings show that the Yo-Yo test and vertical jumps (SJ and CMJ) were correlated with the distance covered by young players at speeds between 15.8-24 km/h. However, no other correlations were observed between field tests and technical performance.

Soccer is an intermittent sport with low, medium, and high intensity demanding workouts, including accelerations, decelerations, jumps, and change of direction. However, the duration of a game and its requirements also demand a high level of aerobic capacity. The Yo-Yo tests are used extensively to estimate aerobic capacity in the field. A potentially strong relationship between performance measured in a field test and the match running performance would help coaches to assess the level of readiness of their players to compete. Many studies have looked into the correlations between match running performance and aerobic performance during specific tests [3, 4, 11]. The aerobic field tests commonly used were the Yo-Yo tests. In particular, Bradley and Noakes, in their study [3] mentioned positive correlations between the Yo-Yo IE2 test and the match running performance. The observed correlation was between the field test performance and the total and high-intensity running distance covered in a match. Similar results were mentioned from another group of researchers [23] who found significant relations of Yo-Yo IR1 test performance with the total and high-intensity running in soccer players. In another study by Castagna et al. [4] correlations between the Yo-Yo IR1 test and the multistage fitness test with several match physical activities (high-intensity running and sprinting) were showed whereas the performance in the Hoff test correlated only with sprint distance. This and most of the above studies reported correlations between performances in various field tests with match running performance. It should be noted that minor differences between investigations are due to the use of different field tests, the GPS systems, or the video analysis system. Besides, the age of young soccer players and the level of biological maturation can also affect the above relationships. Therefore, before generalizing the findings, it would be of interest to perform a more complex study in differentage groups with a similar methodology.

To our knowledge, only three studies have looked into the relationships between anaerobic field tests and match running performance. Rampinini et al. [21] mentioned significant correlations between the ability of the repeated sprint test and the match running performance (very high intensity running and sprinting) whereas no correlations were found with the vertical jump performance. Similar results have been presented by another laboratory [1] which found that the performance in the running-based anaerobic sprint test was significantly correlated with the distance covered at medium intensity running. In contrast to a recent study, the researchers mentioned no correlations between the repeated sprint test and the match running performance [24]. One possible explanation for this dispute could be the fact that the study of Redkva et al. [24] was performed during friendly soccer matches and not official ones. In our study, we found correlations between two kinds of jumps with high intensity running. As above, the use of different tests and differences in the sample (level, age, type of matches – friendly or official) can affect the results of the studies. The repeated sprint test activates a different energy supply mechanism than jumps (glycolysis vs phosphagen system). The jumps are used by the coaches to assess the jumping ability and the power of the players. Therefore, the good jumping ability also implies a high ability to run at a very high speed. Additionally, the phosphagen system supplies energy actions that are as intensive as jumps. High-intensity running is an action where a significant part of the energy is supplied by the same energy system. Therefore, a well-trained phosphagen energy system could increase the ability of a soccer player to cover a longer distance at high intensity.

It is known that sample homogeneity could affect the results in correlation studies [12]. We have to be careful when we want to generalize the findings of the study. However, similar results for the Yo-Yo IR1 and Yo-Yo IE2 tests were also mentioned by previous researchers [23] in soccer players of a similar age and at a competitive level. This indicates that the Yo-Yo IE1 test is probably an appropriate test to estimate aerobic capacity in young soccer players.

In any sport that requires object handling, the technique is a determining performance factor. Thus, in soccer, the technical skill of handling the ball is particularly important and has been the object of research in several studies. Over the past two decades, researchers have focused on the possible relationship between technical abilities and performance obtained in fitness tests. Previous studies [21, 22] showed that players of better teams performed more passes than players of the worst teams during official matches. Also, the numbers of passes were decreased in the second half and this could be a sign of the influence of physical performance on technical actions [7]. Rampinini et al. [22] showed that the deterioration in the Loughborough soccer passing test (LSPT) score was correlated with performance in the Yo-Yo IR1 test. This finding suggested that players with a higher fitness level performed technical actions more correctly than the players with a lower fitness level [2]. Helgerud et al. [11] studied the effect of a training program on the passing ability of soccer players. They found that the improvement of physical fitness led to an increased number of involvements with the ball. In a more recent study [2], researchers mentioned that the total performance at LSPT was positively correlated with many fitness tests (sprint 5 m, 20 m, 30 m, agility – 15 m, ball – 15 m, Illinois agility test). Negative correlations were found between LSPT and SJ and CMJ. All the above studies used field tests for the evaluation of technical performance changes. In our study, we looked into the correlations between performance in field fitness tests and the technical performance during actual soccer matches of young players. Our results are in line with the results of a recent study [20] where researchers used small-sided games and found no correlations between field tests and technical performance. The performance in a specific technical test cannot be compared to the technical performance in an actual soccer match, where the tactical role, individual playing position, the quality of the opponent, and the degree of motivation can affect this factor.

This study indicates that the performance in the Yo-Yo IE1 test and LJ test are good predictors of the intensive match running (15.8-19.7 km/h). Additionally, the Yo-Yo IE1 test and SJ could be used by the coaches to estimate match running performance in higher velocity 19.8-24 km/h.

Conclusions

The results have shown that the majority of field tests were not related to the match running performance in young soccer players. Contrary to the study hypothesis, no anthropometric index was associated with better performance in the soccer game. Also, no fitness indicator was fully correlated with the match running distance and with the technical performance during the game. However, the Yo-Yo IE1 test, LJ, and SJ were the tests that correlated with the distance covered thigh intensity. Additionally, these tests could be used by trainers in an attempt to estimate the readiness of young soccer players to compete.

These findings indicate that the technical performance of young players in actual soccer matches is not correlated with their performance in field fitness tests. According to the UEFA development plan of the young soccer players, players of this age have not perfected yet their technical skills. Additionally, the tactics, the opponent, the adopted style of play could influence the match technical performance. Therefore, in our opinion, more specific technical tests are needed for the evaluation of this kind of performance.

In the last minutes of the games, fatigue can negatively affect the qualitative performance of the technical actions (passes, crosses). For that reason, an analysis where technical actions would be studied every 15 minutes of the game could provide more information on the possible relationship of fitness and execution of technical actions.

Conflicts of Interest
The authors declare no conflict of interest.

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Spatiotemporal analysis of setting per game complex and team rotation in junior volleyball

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Abstract
Introduction. **In volleyball, setting is a critical skill from a technical and tactical point of view, as it affects attack directly: the better the quality of the setter's performance, the more excellent attack actions are carried out by men and women attackers.** Aim of Study. **This study aimed to assess the spatial and temporal characteristics of the setting choices made by junior male volleyball setters and their performance concerning the game complex per match rotation.** Material and Methods. **A three-member group of experienced coaches assessed the setting zones choices, the setting tempo, and the performance of junior male setters from 20 volleyball games of teams competing in the final phase of the 2016 Greek Junior Championship. A five-level ordinal scale was used to evaluate the setting. The test of independence for the categorical variables was carried out using the chi-square test (χ^2). Following the overall independence test, the difference in proportions among all levels of variables was tested.** Results. **Results showed that zone 4 was the junior setters' first choice irrespective of the game complex. More detailed, in Complex II, the most preferable setting zones were 4 and 6, while zone 3 was the primary selection in Complex I. The setting in the first tempo was the most favorite option in Complex I, although second slow tempo was the most frequently used setting option in Complex II. As for the quality of the setting, the dominant value for both complexes was quality level 2.** Conclusions. **In conclusion, the junior male setters directed the ball mainly to position 4 by using the slow 2nd tempo settings irrespective of the game rotation. Moreover, they showed a higher proportion of excellent setting actions and used fast settings (first tempo) more frequently in Complex I than in Complex II.**

KEYWORDS: volleyball, juniors, high level, setter's distribution, rotation, tempo of setting, performance analysis.

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Introduction

Volleyball is probably one of the most popular sports in the world [20]. Therefore, numerous studies have investigated the players' performance to determine the factors that result in improving the effectiveness of training and, consequently, competition. Among those factors, setting is considered to determine the next action's efficacy and, up to a certain level, the final result of the game [6, 18, 21]. Indeed, setting is an essential action in volleyball, not only from the technical point of view but also from the tactical one, as it affects the attack, with the setter being the specialist player who is responsible for organizing the game [6, 21]. The setter is the player that makes the majority of tactical decisions as he or she is responsible for deciding where the ball is to be passed. The setter has to evaluate the limitations encountered concerning the context of the game seeking his or her action to impair the attack-defense of the opposite team [2]. According to Bergeles, Barzouka, & Nikolaidou [5], the higher performance of the setter leads to the higher performance of the attackers. More specifically, the percentages of excellent attack actions carried out by men and women attackers got higher as the quality of the setters' performance got higher.

One of the characteristics of volleyball that distinguishes it from the rest of the team sports is that all players have to pass through all positions of the court and, as a consequence, to adapt in the execution of their skills concerning each position [17]. According to Silva et al. [22], each team has six "teams" that correspond to the six-game rotations since in each rotation the positions, functions, and relations between players are different. The above mentioned cyclic and sequential nature of volleyball [26] results in two major game complexes: the side out complex (CI) and the defense complex (CII) [5]. CI entails organizing the attack [2] and is comprised of the receiving, setting, and attacking actions as well as the attack coverage [21]. The main objective of CI is to neutralize the rival's serve and to employ an offensive organization [19] to gain possession of the serve [16]. CII is known as the defense complex defined as the situation where the opposing team will perform the actions of serve, block, floor defense, set, and counter-attack in sequential order. In CII, the ball does not reach the setter in the best conditions [7, 11]. Consequently, the setting tempo is slow (i.e. 2nd and 3rd tempo) and setting is mostly carried out at the edges of the net [11]. Regardless of the previous action efficacy, high-level setters can achieve optimum sets under difficult circumstances [19, 27]. This results in the setters being able to diversify the attack of their teams, producing a high variability of their setting actions [12] concerning their spatial or/and their temporal characteristics. Besides, the attack tempo is considered to be a crucial variable when analyzing the relationship between attack and defense [14]. Recent studies revealed that in CI the elite male setters used mainly quick setting actions [8]. Although zone 4 was their first choice, their distribution strategy included all setting zones [4, 24]. This variability caused the teams to be less predictable in the attack, destabilizing the opposing block in this way [14].

What is worth mentioning about the relavant literature is that the majority of the related studies have analyzed the players'and team's performance in several adult high-level volleyball tournaments while there is limited research in younger age groups. Taking into account that physical characteristics and skill level of junior male players may not be as well developed as in the adults, the lack of specific information about setting may produce misleading effects on the training and competition evaluation in junior men's volleyball teams. That is the reason why it could be of interest to analyze the skill of setting in junior teams.

Aim of Study

The present study aimed to assess the spatial and temporal characteristics of the setting choices made by junior male volleyball setters and their performance concerning the game complex per match rotation.

Material and Methods

A three-member group of experienced coaches assessed the setting zones' choices as well as the setting tempo and the performance of junior male setters from 20 volleyball games of teams competing in the final phase of the 2016 Greek Junior Championship. Firstly, the coaches were asked to observe and categorize the setting quality according to the 5-level tactical rating scale proposed by Eom and Schutz [9], which quantifies the effectiveness of skill performance within a range of points from 0 to 4. Secondly, the coaches were asked to observe and categorize the setting choices according to the consequent attacking area, i.e. to zones 1, 2, 3, 4, 5, 6, and the setting tempo. The tempo of setting is defined as the combination of two variables: the moment when the setter contacts the ball and the start of the attacker approach. The categories are: tempo 1 (the attacker jumps simultaneously or before the setter touches the ball), tempo 2 fast (the attacker starts the approach when the ball leaves the setter's hands), tempo 2 slow (the attacker starts the approach when the ball reaches the first half of its upward trajectory after leaving the setter's hands), tempo 3 (the attacker starts the approach when the ball reaches the highest point of its trajectory after leaving the setter's hands).

The sample for this analysis consists of 2827 setting actions (Complex I = 1930, Complex II = 897). Intra-rater and inter-rater reliability coefficients were found to be r = 0.983 and r = 0.984 respectively, indicating very high consistency in the assessment procedure.

The test of independence for the categorical variables "game complex" and "setting zone" was carried out using the χ^2 test for each one of the six levels of the variable game rotation (implemented with the statistical package SPSS v. 17). Following the overall independence test, we tested the difference in proportions between the two-game complexes for each level of the "setting zone" variable in each one of the six levels of the variable "game rotation" (test of proportion differences based on the normal distribution) using the statistical package Statgraphics Plus v. 5.1. The same procedure was followed for the variables "game complex" and "setting tempo" as well as for the variables "game complex" and "setting performance".

Results

Setting zone choices of junior setters in relation to game complex per game rotation

The statistical analysis showed that there was a statistically significant relationship (χ^2 test, p-value < 0.05) between the game complex and setting zone in 4 of 6 game rotations (Table 1). Moreover, after testing the difference in proportions of the setting zone between game complexes within each level of the "game rotation" variable, it was found that 1) in rotation 1, junior setters in CI carried out a significantly higher

Table 1. Setting zone choices per game complex and rotation

R	C	Setting zones 1	2	3	4	5	6	χ2
		% (N)	% (N)	% (N)	% (N)	% (N)	% (N)	Value Sig.
1	CI	7.5 (25)	27.2 (91)	22.1 (74)	39.4 (132)	0.0 (0)	3.9 (13)	21.423
	CII	9.6 (16)	16.2 (27)	12 (20)	54.5 (91)	0.0 (0)	7.8 (13)	0.001
	Z	–0.81	2.74	2.73	–3.21		–1.85	
	P	ns	0.006	0.006	0.001		0.06	
2	CI	7.3 (21)	20.4 (59)	19 (55)	50.9 (147)	0.0 (0)	2.4 (7)	8.655
	CII	4.5 (6)	18.8 (25)	17.3 (23)	51.1 (68)	0.0 (0)	8.3 (11)	0.07
	Z	1.09	0.38	0.42	–0.04		–2.79	
	P	ns	ns	ns	ns		0.005	
3	CI	8.1 (22)	19.6 (53)	20 (54)	48.5 (131)	0.0 (0)	3.7 (10)	7.967
	CII	3.7 (4)	21.1 (23)	11 (12)	59.6 (65)	0.0 (0)	4.6 (5)	0.093
	Z	1.54	–0.33	2.09	–1.96		–0.41	
	P	ns	ns	0.04	0.05		ns	
4	CI	9.7 (31)	17.9 (57)	22 (70)	47.2 (150)	0.0 (0)	3.1 (10)	15.081
	CII	9.4 (12)	17.3 (22)	8.7 (11)	56.7 (72)	0.0 (0)	7.9 (10)	0.005
	Z	0.09	0.15	3.28	–1.81		–2.21	
	P≤	ns	ns	0.001	ns		0.03	
5	CI	9.2 (32)	18.4 (64)	20.4 (71)	48.3 (168)	0.0 (0)	3.7 (13)	15.844
	CII	8.2 (14)	17.1 (29)	8.8 (15)	57.6 (98)	0.0 (0)	8.2 (14)	0.003
	Z	0.37	0.36	3.33	–1.99		–2.17	
	P≤	ns	ns	0.001	0.05		0.03	
6	CI	7 (26)	24.3 (90)	20 (74)	45.7 (169)	0.0 (0)	3 (11)	26.901
	CII	6.8 (13)	17.8 (34)	9.4 (18)	55.5 (106)	0.5 (1)	9.9 (19)	0.001
	Z	0.09	1.76	3.21	–2.2		–3.44	
	P≤	ns	0.08	0.001	0.03		0.001	
Sum	CI	8.1 (157)	21.5 (414)	20.6 (398)	46.5 (897)	0.0 (0)	3.3 (64)	
	CII	7.2 (65)	17.8 (160)	11 (99)	55.7 (500)	0.1 (1)	8 (72)	
	Z	0.83	2.27	6.24	–4.55		–5.45	
	P≤	ns	0.02	0.001	0.001		0.001	

Note: C – game complex, R – game rotation

proportion of setting (p-value < 0.05) to zones 2 and 3 (27.2% and 22.1%) in comparison to CII (16.2% and 12%), while they carried out a significantly higher proportion of setting (p-value = 0.001) to zone 4 during CII than during CI (54.5% vs 39.4%), 2) in rotation 2, junior setters in CII carried out a significantly higher proportion of setting (p-value = 0.005) to zone 6 (8.3%) compared to CI (2.4%), 3) in rotation 3, junior setters performed a significantly higher proportion of setting to zone 3 in CI (20%) compared to 11% in CII (p-value < 0.05) and a lower proportion of setting to zone 4 (48.5%) compared to 59.6% in CII (p-value = 0.05), 4) in rotation 4, junior setters performed a significantly higher proportion of setting to zone 3 in CI (22%) compared to 8.7% in CII (p-value = 0.001) and a lower proportion of setting to zone 6 (3.1%) compared to 7.9% in CII (p-value < 0.05), 5) in rotation 5, junior setters performed a significantly higher proportion of setting to zone 3 in CI (20.4%) instead of 8.8% in CII (p-value < 0.05), while they performed a lower proportion setting to zone 4 (48.3%) and zone 6 (3.7%) compared to 57.6% and 8.2%, respectively, in CII (p-value ≤ 0.05), and 6) in rotation 6, junior setters performed a statistically significantly higher proportion of setting to zone 3 in CI (20%) instead of 9.4% in CII (p-value = 0.001), while they performed a lower proportion setting to zone 4 (45.7%) and zone 6 (3.0%) compared to 55.5% and 9.9%, respectively, in CII (p-value ≤ 0.05).

In total, irrespective of the "game rotation", junior setters in CI carried out a statistically significantly higher proportion (p-value < 0.05) of setting to zones 2 and 3 compared to CII (21.5% vs 17.8% and 20.6% vs 11%), while in CII they carried out a statistically significantly higher proportion (p-value = 0.001) of setting to zones 4 and 6 compared to CI (55.7% vs 46.5% and 8% vs 3.3%).

Tempo of setting of juniors setters in relation to the game complex per game rotation

The statistical analysis showed that there is a statistically significant relationship (χ^2 test, p-value < 0.05) between game complex and setting tempo in 5 of the 6 game rotations (Table 2). Furthermore, after testing the difference in proportions of the setting tempo between game complexes, within each level of the "game rotation" variable it was found that: (a) in rotation 2, statistical analysis did not show a significant relation between game complexes and setting tempo, (b) in rotations 1, 3, 4, 5 and 6, junior setters in CI carried out a significantly higher proportion of setting 1st tempo (21.5%, 20%, 21.7%, 19,5%, and 19,5%) compared to 12%, 11%, 8.7%, 8.8%, and 9.4%, respectively, in CII (p-value < 0.05) and (c) in rotations 1, 3, 4, 5 and 6, junior setters in CII carried out a statistically significantly higher proportion of setting 2nd slow tempo (84.4%, 86.2%, 85.8%, 85.3%, and 83.2%) compared to 71.9%, 72.6%, 71.7%, 74.7%, and 72.7%, respectively in CI (p-value < 0.05).

Table 2. Setting tempo per game complex and rotation

R	C	Setting tempo				χ^2
		1st	2nd fast	2nd slow	3rd	Value
		% (N)	% (N)	% (N)	% (N)	Sig.
1	CI	21.5 (72)	0.3 (1)	71.9 (241)	6.3 (21)	10.352
	CII	12 (20)	0.6 (1)	84.4 (141)	3 (5)	0.016
	Z	2.59	–0.5	–3.09	1.57	
	P	0.009	ns	0.002	ns	
2	CI	18.3 (53)	0.7 (2)	73 (211)	8 (23)	2.879
	CII	17.3 (23)	0.0 (0)	78.2 (104)	4.5 (6)	0.411
	Z	0.25	–	–1.14	1.32	
	P	ns	ns	ns	ns	
3	CI	20 (54)	0.7 (2)	72.6 (196)	6.7 (18)	8.449
	CII	11 (12)	0.0 (0)	86.2 (94)	2.8 (3)	0.038
	Z	2.09	–	–2.83	1.5	
	P	0.04	ns	0.005	ns	
4	CI	21.7 (69)	0.6 (2)	71.7 (228)	6 (19)	11.258
	CII	8.7 (11)	0.8 (1)	85.8 (109)	4.7 (6)	0.010
	Z	3.22	–0.23	–3.13	0.54	
	P	0.001	ns	0.002	ns	
5	CI	19.5 (68)	0.9 (3)	74.7 (260)	4.9 (17)	9.971
	CII	8.8 (15)	0.6 (1)	85.3 (145)	5.3 (9)	0.019
	Z	3.12	0.36	–2.74	–0.2	
	P	0.002	ns	0.006	ns	
6	CI	19.5 (72)	1.1 (4)	72.7 (269)	6.8 (25)	9.788
	CII	9.4 (18)	1 (2)	83.2 (159)	6.3 (12)	0.020
	Z	3.08	0.11	–2.77	0.23	
	P	0.002	ns	0.006	ns	
Sum	CI	20.1 (388)	0.7 (14)	72.8 (1405)	6.4 (123)	
	CII	11 (99)	0.6 (5)	83.8 (752)	4.6 (41)	
	Z	5.96	0.304	–6.4	0.23	
	P≤	0.001	ns	0.001	ns	

Note: C – game complex, R – game rotation

In total, irrespective of the "game rotation", junior setters in CI carried out a statistically significantly higher proportion (p-value = 0.001) of setting 1st tempo compared to CII (20.1% vs 11%), while in CII they carried out a statistically significantly higher proportion (p-value = 0.001) of setting 2nd slow tempo compared to CI (83.8% vs 72.8%).

Setting performance of junior setters in relation to game complex per game rotation

The statistical analysis showed that there is a statistically significant relationship (χ^2 test, p-value < 0.05) between game complex and setting performance in 2 of 6 game rotations (Table 3). Besides, after testing the difference in proportions of the setting performance between

Table 3. Setting performance per complex and rotation

R	C	Setting performance 0 % (N)	1 % (N)	2 % (N)	3 % (N)	4 % (N)	χ2 Value Sig.
1	CI	2.7 (9)	6.3 (21)	41.8 (140)	17.3 (58)	31.9 (107)	4.199
	CII	1.8 (3)	3.6 (6)	43.7 (73)	22.8 (38)	28.1 (47)	0.380
	Z	0.62	1.26	–0.41	–1.48	0.87	
	P	ns	ns	ns	ns	ns	
2	CI	3.5 (10)	8 (23)	42.9 (124)	19.7 (57)	26 (75)	3.777
	CII	3.8 (5)	5.3 (7)	36.8 (49)	20.3 (27)	33.8 (45)	0.437
	Z	–0.15	1.00	1.18	–0.14	–1.65	
	P	ns	ns	ns	ns	ns	
3	CI	1.5 (4)	7.4 (20)	46.3 (125)	19.3 (52)	25.6 (69)	11.007
	CII	5.5 (6)	2.8 (3)	44 (48)	27.5 (30)	20.2 (22)	0.026
	Z	–2.19	1.7	0.41	–1.75	1.11	
	P	0.03	ns	ns	0.08	ns	
4	CI	2.8 (9)	5.7 (18)	44.7 (142)	17.9 (57)	28.9 (92)	1.692
	CII	2.4 (3)	7.1 (9)	46.5 (59)	20.5 (26)	23.6 (30)	0.792
	Z	0.23	–0.34	–0.34	–0.64	1.13	
	P	ns	ns	ns	ns	ns	
5	CI	1.1 (4)	6.6 (23)	43.7 (152)	23.3 (81)	25.3 (88)	1.544
	CII	0.6 (1)	5.9 (10)	48.2 (82)	20 (34)	25.3 (43)	0.819
	Z	0.55	0.31	–0.97	0.85	0.0	
	P	ns	ns	ns	ns	ns	
6	CI	1.4 (5)	9.7 (36)	44.3 (164)	19.7 (73)	24.9 (95)	9.914
	CII	2.1 (4)	6.8 (13)	39.3 (75)	30.9 (59)	20.9 (40)	0.042
	Z	–0.62	1.15	1.13	–2.96	1.06	
	P	ns	ns	ns	0.003	ns	
Sum	CI	2.1 (41)	7.3 (141)	43.9 (847)	19.6 (378)	27.1 (523)	
	CII	2.5 (22)	5.4 (48)	43 (386)	23.9 (214)	25.3 (227)	
	Z	–0.67	1.88	0.45	–2.61	1.01	
	P	ns	ns	ns	0.009	ns	

Note: C – game complex, R – game rotation

game complexes within each game rotation, it was found that in rotation 3 junior setters in CII carried out a statistically significantly higher proportion of setting errors evaluated by 0 (5.5%) compared to 1.5% in CI (p-value=0.03), while in rotation 3, they performed in CII a statistically significantly higher proportion of setting with quality grade 3 (27.5%) instead of 19.3% in CI (p-value = 0.003). In total, irrespective of the "game rotation", junior setters in CII carried out a statistically significantly higher proportion (p-value<0.05) of setting with quality grade 3 compared to CI (23.9% vs 19.6%).

Discussion

The purpose of this study was to assess the spatial and temporal characteristics of the setting choices made by junior male volleyball setters and their performance concerning the game complex per match rotation. Our results revealed that irrespective of the game rotation and complex, junior setters' distribution strategy included most of the setting zones with zone 4 being their first choice. This corroborates the results of previous studies [4, 25] which have found that elite male setters directed their settings mainly to zone 4. The choice of the junior setters could be partially explained by the ability of the left side wing spikers to attack effectively [8, 15] or by the fact that under difficult situations setters very often sent the ball to position 4 [10] in a slower tempo, especially when they have to move outside the ideal setting area [2]. According to Costa et al. [7] in elite youth male volleyball, the serve-reception percentage that resulted in organized attacks was 74.2% of the total. On the contrary, the offensive actions' percentage that resulted in the continuity of the game was found to be 34.9% of the total while almost half of it (47.1%) did not allow organized counter-attacks. This may explain why the setters of the current study chose the setting to zone 4 more frequently in CII compared to CI. Besides, even adult male setters in difficult situations very often send the ball to position 4 attackers [10], who are characterized as security players because of their ability to attack effectively [15] even when they have to confront a compact double or triple block [3]. This happens especially when the opponent setter is in the attack zone making the block less efficently.

Another interesting finding of the current study was that irrespective of the game phase (i.e. when the setter was in the attack or the defense zone) the setting distribution to zone 1 was not differentiated between the side out and the transition complex. However, when the setters were in rotations 1 and 6, they sent the ball to zone 2 more frequently in CI compared to CII. An almost similar differentiation between the two complexes was also seen in the setting distribution to zone 3 in most of the team rotations. This may be because in CI the setters had enough time to concentrate on the carrying out of a more complete tactical plan than in CII. Besides, it is known that in CI the initial conditions are rather stable and predictable since the ball is received from an action that has less contextual interference (i.e. the serve) and is executed far from the net, thus creating favorable conditions to the offensive organization [27]. On the contrary, in CII the attack organization becomes more difficult because the ball comes from the attack, which is executed near the net and with a steeper trajectory [13]. Taking into consideration the aforementioned complex differences regarding the initial conditions that interfere with the attack organization, it would be logical to hypothesize that the highest setting distribution frequency found in the current study towards zone 6 did not rely upon a predetermined offensive tactical plan but on the restrictions imposed by the previous action. This seems to be quite different in the case of elite men setters who were found to send a remarkable percentage of their settings to positions 3 and 6 only in the case of an excellent previous defensive action [23]. However, this discrepancy may be explained by the physical characteristics and the skill level of the junior players which may not have been as well developed as in the case of the elite adult players.

Concerning the attack tempo, this study showed that irrespective of the game complex and team rotation, the setters used mainly the slow 2nd tempo settings but rarely the fast second (0.7%) and the third tempo (5.8%). The latter contradicts partially the results of Costa et al. [7] who found that 34.4% of the attacks which were carried out during the 2007 World Youth Male Championship were 3rd tempo attacks. The above-mentioned discrepancy denoted the tendency of the game to become faster even in the transition phase which is characterized by unpredictable and unstable initial conditions [13]. According to Costa et al. [7] playing fast in the transition phase is decisive in creating favorable conditions for delaying the blocking action of the opponent and thus for increasing the chances of making the point. On the other hand, the same authors stated that in the side-out phase the attack effect is not dependent on its speed since playing fast in this complex is common. However, this study showed that in CI the proportion of the fast settings (1st tempo) carried out by the junior setters was higher compared to CII probably because CI offers more stable conditions for the offensive organization [13].

Concerning the setting performance, most of the setting actions of the junior setters were evaluated as "good" probably because the lack of synchronization between the setter and the attackers allowed the opponent team to form a compact double or even triple block. It is worth mentioning that in CI the proportion of the excellent setting actions in most of the game rotations was higher compared to CII. On the contrary, the proportion of the setting actions which were evaluated as very good were found to be higher in CII than in CI in almost all the game rotations. Additionally, when the setter was in the attack zone and specifically in rotation 3, the proportion of the setting errors was found to be higher in CII than in CI. These differences between complex I and II are associated with worse conditions to perform an organized attack in CII probably due to the first touch difficulties [7, 13]. Besides, the current study showed that the attack tempo, which seemed to be a strong indicator of the offensive organization [1], was faster in CI than in CII.

Conclusions

In conclusion, the junior male setters directed the ball mainly to position 4 by using–irrespective of the game rotation–the slow 2nd tempo settings. Moreover, they showed a higher proportion of excellent setting actions and used fast settings (1st tempo) more frequently in CI than in CII.

Conflicts of Interest

The authors declare no conflict of interest.

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Diversification of the physical and sport education syllabi and its effects on the musculoskeletal system in young female students

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Abstract
Introduction. **The prevalence of musculoskeletal disorders in the school-age population might lead to the occurrence of vertebrogenic diseases in adulthood, which stresses the importance of timely primary prevention in the form of health-oriented compensatory exercise programs.** Aim of Study. **This pilot study presents targeted diversification of physical and sport education syllabi focused on the improvement of the musculoskeletal system's functions in young female students, including body posture, dynamic capacity of the spine, and the muscle system.** Material and Methods. **The study group comprised of 24 high school female students, divided into experimental (EG; 16.32 ± ± 0.32 years) and control (CG; 16.56 ± 0.56 years) groups. The data were acquired using standardized methods focused on the functional capacity of the musculoskeletal system.** Results. **In contrast to the control (V_{1-2}) stage, the experimental (V_{3-4}) stage involved diversification of physical and sport education syllabi for the EG subjects, which led to significant changes in their overall body posture ($p < 0.01$). The most significant changes occurred in the abdominal segment and pelvic inclination ($p < 0.01$). The dynamic capacity of the spine ($p < 0.01$), in all five tests, also changed in the EG participants. Bad movement habits affected the quality of the muscle system in the members of both groups. We noted the most significant changes ($p < 0.01$) in m. trapezius pars superior and m. levator scapulae, the muscles responsible for neck pain. The hip flexors contributed significantly ($p < 0.05$) to lower back pain. We found significant differences between the EG and the CG. The EG participants demonstrated improvements in all monitored segments.** Conclusions. **The results obtained by the EG significantly prove how important it is to diversify physical and sport education syllabi to improve health and the functional capacity of the musculoskeletal system in the school-aged population.**

KEYWORDS: musculoskeletal system, physical and sports education, student.

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Introduction

Even ancient books and documents highlight the unity of body and soul in terms of human irreplaceableness and uniqueness. Nowadays, it takes a lot of effort to comprehend the philosophy and essence of health due to opportunities and snares lurking in the 21st century consumer society [5].

Physical activity is closely related to health, quality of life, and lifestyle. It is a multidimensional and complex behavior to measure; its various domains are often misunderstood. It has a fundamental role in the prevention and treatment of chronic diseases. What is more, physical activity is a key commodity for maintaining the proper physical and mental functioning of the human body [4]. Its deficiency significantly affects people's physical fitness, work performance, and health condition [24]. Statistics of health insurance companies in the USA, Canada as well the European Union member states, including Slovakia [9], attest to this fact and point to serious economic and social consequences.

Over the past two decades, the current lifestyle of the school-age population in Slovakia has become hypokinetic [3], which has led to an increase in the prevalence of lifestyle chronic diseases [6], including the musculoskeletal disorders [17]. Insufficient primary prevention of musculoskeletal disorders in childhood leads to vertebrogenic diseases in adulthood, the prevalence of which ranges from 60% to 80%. The most common and primary symptom of musculoskeletal changes and diseases is pain. As many as three-quarters of patients complain about back pain [21], the prevalence of which is 22% in Europe, including children. 46% to 53% of children feel the pain at least once in their lives while 15% of them suffer from persistent pain. The situation in Slovakia, where the occurrence of pain tripled between the years 1996 and 2008, is getting worse as well. The incidence of idiopathic pain syndromes among children in Slovakia ranges from 4.2% to 15.5%. According to Lewit [16], the primary symptom of cervical spine disorders in children is a headache, which is not given enough attention. Moreover, it has been proven that muscle imbalance in childhood can result in later pain. The most common symptoms of functional disorders of the spine in healthy children are sacroiliac shift and functional disorders in the region of the upper cervical spine connected with different types of headaches. Musculoskeletal pain is more commonly secondary and has an additive effect. It can be at the forefront of the whole pain syndrome. Continuous overloading results in coordination disorders and inadequate muscle innervation, which leads to deterioration of degenerative processes. In addition to excitation of nociceptors, segmental disorders also cause reflex muscle tension and further excitation of nociceptors. Consequently, muscles shorten and become weaker, bones are demineralized and tendon entheses become shorter [16].

The aforementioned facts prove how necessary it is to teach school-aged children to be responsible for their health and to search for new preventive measures in their lifestyle. Besides the family [13], physical and sports education at schools can also play an important role [8, 25]. Health, quality of life, lifestyle, and physical activity of the school-age population are becoming widely discussed topics also concerning contemporary physical and sports education at elementary and secondary schools both in Slovakia and abroad [1, 20]. These issues are examined also because the number of school-aged children in Slovakia, who are excused from compulsory physical and sports education owing to different diseases and disorders, is increasing (8% to 15%). Similarly, the number of pupils who do not exercise rises. The percentage of boys who do not exercise ranges from 27.7% to 39.6%, and the percentage of girls who do not exercise ranges between 38.2% and 48.1% [3, 4]. According to the findings reported by the Ministry of Education, Science, Research and Sports of the Slovak Republic, approximately 30% of the school-age population regularly excuse themselves from physical and sport education classes even though there was the major reform of the education system in Slovakia, including physical and sports education in 2008. The aim and the focus of physical and sports education shifted markedly from performance-based classes to the development of pupils' and students' competences and values and attitudes towards their health. The goals of physical and sports education are associated with health care and the development of a healthy lifestyle. Individual teaching methods in physical and sports education focus on the acquisition of habits, attitudes, and knowledge related to physical activity, health, and a healthy lifestyle in the school-age population [3]. In terms of primary prevention of diseases of the musculoskeletal system [15], which is one of the determinants of health, physical and sports education requires interventions [7] in the form of health-oriented exercise programs. These programs help to improve body posture (postural stability), functions of the spine and the muscle system in school-aged children [14, 19, 28], support their adequate development and improve the quality of their health at present and in the future.

Aim of Study

The study aimed to purposefully diversify the physical and sports education syllabi regarding the improvement of the functional capacity of the musculoskeletal system in young female students. This diversification was focused on body posture, the dynamic capacity of the spine, and the muscle system.

Material and Methods

Sample and procedure

The entire study group consisted of 24 female students in the second grade of a high school. The experimental group (EG) comprised 12 students with an average age 16.32 ± 0.48 years (body height 168.36 ± 7.21 cm, body weight 57.62 ± 6.51 kg) and the control group (CG) also consisted of 12 students whose average age was 16.56 ± 0.56 years (body height 167.87 ± ± 6.83 cm, body weight 56.36 ± 4.61 kg). The members of both groups were not interested in physical and sports education and did a physical activity in their free time only occasionally and with low intensity. Furthermore, all the girls complained about pain in the cervical and lumbar regions of the spine, which is regarded as functional disorders of the spine.

Measurements

The pedagogical experiment was conducted in three stages during the school year 2018/2019. The first stage of the study (09/2018) was focused on initial examination (V_1) of the EG and CG participants' musculoskeletal system (body posture, the dynamic capacity of the spine, the muscular system) performed by a physiotherapist. The results of the preventive medical examination confirmed that none of the girls suffered from any serious organic or neurological diseases. Pain intensity was measured using the visual analog scale (VAS). The experiment then continued with physical and sport education classes taught according to the School Education Programme. The second assessment (V_2) of the EG and CG members' musculoskeletal system took place in December. The first stage also included analysis of the classes focused on the syllabi and the use of individual exercises within each physical and sports education lesson. The second stage (01/2019) of the experiment included evaluation of the EG and CG members' musculoskeletal system again (V_3). During this stage, the subjects in the EG had different physical and sport education lessons. They carried out 45-minute health-oriented exercise programs (based on the Acral Coactivation Therapy – ACT) led by their PE teacher twice a week (Tuesday and Thursday) over three months. These programs were also based on the functional capacity of the EG subjects' musculoskeletal system (V_{1-2}).

The ACT exercise programs, introduced by Palaščáková Špringrová [23], are based on children's motor development and its patterns. The basic principle lies in pressing against palm and heel roots or toes, which results in the straightening of the spine. It is essential that the exercises are focused mainly on the closed kinetic muscle chains. The exercise programs based on the ACT method involve movement patterns that are most frequently used in everyday activities of the so-called ADL (Active Daily Life). The subjects wore the FHAS (functional hand arch support) gloves, which supported arches of their hands. This maintained muscle coactivation throughout the entire period of exercise in basic and more dynamic transitions.

The CG members continued having physical education lessons in line with the syllabi determined by the School Education Program. The third stage of the study (04/2019) involved final assessments (V_4) of the monitored factors of the musculoskeletal system in the EG and CG members, which were further analyzed.

We acquired data on the functional capacity of the musculoskeletal system (body posture, the dynamic capacity of the spine and the muscle system) in both groups during the initial (V_1, V_3) as well as the final assessments (V_2, V_4).

Static body posture was evaluated using the method invented by Thomas and Klein and modified by Mayer [11]. This method assesses five segments of body posture: a) head and neck posture, b) shape of the chest, c) the abdominal segment and pelvic inclination, d) curvature of the spine, e) shoulder height and position of the shoulder blades. Each segment was assessed by points 1, 2, 3, 4 (from the best to the worst), where a total of these points classifies the overall body posture of the subjects:

I. Ideal body posture .... 5 points
II. Good (almost ideal) body posture .... 6-10 points
III. Poor body posture .... 11-15 points
IV. Bad body posture.................................. 16-20 points

Assessment of the muscle system, which was focused on hyperactive postural muscles that tend to shorten (m. trapezius pars superior, m. levator scapulae, m. pectoralis major, m. quadratus lumborum, m. erector spinae, m. adductores coxae, m. iliopsoas, m. rectus femoris, m. tensor fasciae late, m. knee flexors, m. triceps surae) and hypoactive antagonists with the predominance of phase activity that tend to weaken (deep neck flexors, lower fixators of the scapula, m. abdominis, abductors of the hip joint, extensions of the hip joint), was based on functional diagnostics of the musculoskeletal system Vojtaššák [29].

Aspect-palpation assessment of the dynamic capacity of the spine consisted of six tests [29]: Schober's test (the lumbar spine, normative value: 4-6 cm), Stibor's test (the lumbar and thoracic spine, normative value: 7.5--10 cm), Otto's test (the thoracic spine, normative value: 6 cm), Thomayer's test (overall flexibility of the spine, normative value: 0-2 cm), right and left lateral flexion (flexibility of the lumbar spine to the sides, normative value: 20-22 cm). The intensity of pain was measured using the visual scale (VAS), which is a Likert 11-point scale: 0 = without pain, 10 = the worst possible pain [29].

Statistical analyses

We processed the acquired quantitative and qualitative data using mathematical and statistical procedures: arithmetic mean, standard deviation, and Wilcoxon t-test ($p < 0.01\%$, $p < 0.05\%$). Practical and objective significance was assessed through effect size (r). We used the Mann–Whitney U test ($M_{WU\text{-}test}$ $p < 0.01$, $p < 0.05$) to verify the degree of conformity between two independent groups. The relationship between the selected factors of the musculoskeletal system was assessed using Spearman's correlation coefficient (r_s). We also used the logic analysis and synthesis methods as well as inductive and deductive procedures and comparisons. The data were processed with the R-Project statistical program.

Results

Concerning the aim of the study, we present the results that should be viewed from a wider social and economic perspective as informational and explanatory regarding the current health status of the school-age population.

The initial assessment (V_1) revealed that in both EG and CG the poor body posture was the most prevalent. Eight subjects from the EG had poor posture and 4 subjects had good body posture (the 2nd category). Similarly, 9 subjects from the CG had poor body posture (the 3rd category) and 3 subjects had good body posture. None of the subjects from the EG or the CG had ideal body posture (1st category). The first three months ($V_{1\text{-}2}$) of physical and sports education lessons led by the PE teacher according to the School Educational Program did not lead to any significant changes ($p > 0.05$) in body posture, in either group. However, the health-oriented intervention exercise program that the subjects from the EG performed during three months ($V_{3\text{-}4}$) resulted in positive changes in their body posture. All the subjects in the EG (n = 12) underwent positive changes with an average of 2.86 points. The final assessment (V_4) revealed that 10 girls belonged to the second category (good posture) and two girls fell into the first category (ideal body posture). These changes were significant ($p < 0.01$) with the large effect size value ($r = 0.62$). However, we did not find any significant changes in overall body posture in any subjects from the CG during the ($V_{3\text{-}4}$) period. Evaluation of significant differences between the EG and the CG proved the positive effect of the applied exercise program with significant improvement in the EG ($M_{WU\text{-}test} = 9.267$, $p < 0.01$).

As far as other segments of body posture are concerned, the worst values during the first stage ($V_{1\text{-}2}$) in both EG and CG regarded head and neck posture, the shape of the chest and pelvic inclination. Physical and sports education lessons taught according to the School Education Programme during the second stage ($V_{1\text{-}2}$) did not lead to any significant changes ($p > 0.05$) in individual segments of body posture in either group. During the third stage ($V_{3\text{-}4}$), however, we noted positive changes in all five segments of body posture in the EG subjects. The segments I ($r = 0.57$) and III. ($r = 0.57$) were at the one percent significance level, and the segments II, IV and V at the five percent significance level (Table 1). There were no significant changes in any body posture segments in the CG ($p > 0.05$) during the $V_{3\text{-}4}$ stage. Analysis of significant differences between the EG and the CG proved the positive effect of the applied exercise program with significant improvement in the experimental group ($M_{WU\text{-}test} = 9.291$, $p < 0.01$).

Table 1. Changes in individual body posture segments during the experimental period ($V_{3\text{-}4}$) in experimental group (n = 12)

Body posture segment	p-value	Effect size (r)
I. Head and neck posture	0.0053	0.57
II. Shape of the chest	0.0420	0.41
III. The abdominal segment and pelvic inclination	0.00512	0.57
IV. Curvature of the spine	0.0423	0.41
V. Shoulder height and position of the shoulder blades	0.0168	0.48

In the first (V_1) and second ($V_{1\text{-}2}$) study stage, we assessed the dynamic capacity of the spine in both EG and CG and we found that most of the subjects demonstrated deviations and did not have normative values in all the tests, which meant that all the subjects demonstrated the lower dynamic capacity of the spine. The final assessment in the second stage (V_2) revealed only minimum changes, which were not significant ($p > 0.05$). The experimental period resulted in positive significant changes ($V_{3\text{-}4}$) ($r = 0.62$, $p < 0.01$) in the EG members, in all five segments of the spine dynamic capacity. The subjects in the CG did not demonstrate any significant changes in the monitored factors of the spine dynamic capacity ($p > 0.05$) in the $V_{1\text{-}2}$ and $V_{3\text{-}4}$ stages. Evaluation of significant differences between the EG and the CG proved the positive effect of the applied exercise program with significant improvement in the EG ($M_{WU\text{-}test} = 9.331$, $p < 0.01$).

The initial assessments in the (V_1) and ($V_{1\text{-}2}$) stages revealed that all the members of the EG and the CG had shortened and weakened muscle groups without significant changes ($p > 0.05$) or differences ($p > 0.05$) between the groups. In the $V_{3\text{-}4}$ stage, the subjects from the EG demonstrated positive changes in the muscle groups that tend to shorten: m. trapezius pars superior

($r = 0.63$, $p < 0.01$), m. levator scapulae ($r = 0.61$, $p < 0.01$), m. pectoralis major ($r = 0.41$, $p < 0.05$), m. erector spinae ($r = 0.60$, $p < 0.01$), m. iliopsoas ($r = 0.42$, $p < 0.05$), the knee flexors ($r = 0.44$, $p < 0.05$) and m. triceps surae ($r = 0.45$, $p < 0.05$).

Similarly, we noted the changes in the muscle groups that have a tendency to weaken: deep neck flexors ($r = 0.41$, $p < 0.05$), lower fixators of scapula ($r = 0.43$, $p < 0.05$), abductors of the hip joint ($r = 0.45$, $p < 0.05$), m. abdominis ($r = 0.54$, $p < 0.01$) and extensions of the hip joint ($r = 0.51$, $p < 0.01$). In the (V_{3-4}) stage, we did not find and significant changes in the muscle system in the members of the CG. The significant changes between the EG and the CG proved the positive effect of the applied exercise programme on the muscle system with significant improvement in the experimental group: $M_{WW\text{-}test} = 8.693$, $p < 0.01$ and $M_{WU\text{-}test} = 5.013$, $p < 0.05$. Having assessed both EG and CG, we found out that forward head posture contributes significantly to the development of functional disorders of m. trapezius pars descendens ($r_s = 0.661$, $p < 0.05$) and m. levator scapulae ($r_s = 0.661$, $p < 0.05$). Furthermore, a shortening of m. trapezius pars descendens and m. levator scapulae has a significant effect ($r_s = 0.661$) on the cervical spine, resulting in pain. Moreover, the protruding abdomen in both EG and CG significantly affected ($r_s = 0.709$, $p < 0.05$) functional capacity of m. erector spinae. The hip flexors contributed significantly ($r_s = 0.638$, $p < 0.05$) to occurrence of pain in the lumbar spine. In the V_{3-4} period, the subjects in the EG did not experience any pain in the cervical and lumbar spine, unlike the members of the CG.

The positive finding of our study is that the EG participants demonstrated significant changes ($p < 0.05$) (Table 2) in the (V_{3-4}) stage, which resulted in improvement and stabilization of low back pain in contrast to the CG subjects ($p > 0.05$) throughout the whole (V_{1-4}) period. As a result, we found significant differences between the EG and the CG ($r = 0.92$, $p < 0.05$).

Discussion

In our opinion, diversification of the physical and sports education syllabi had a positive impact as the participants of the EG demonstrated overall improvement in all monitored segments of the musculoskeletal system and their back pain stabilized. It is important to mention that the physical and sports education syllabus applied in the V_{3-4} stage was based on the assessment of the musculoskeletal system in the participants of the EG while the subjects in the CG had physical and sports education classes taught according to the School Education Program. As far as the healthy development of the school-age population is concerned, even the smallest changes in their lives can have a tremendous impact on their health. In practice, it means that more respect and attention should be paid to the health-oriented fitness of the school-age population, which involves also the musculoskeletal system. The truth is that this system is not given enough consideration in the Slovak physical and sport education syllabi, which need intervention in terms of postural exercise programs focused on pain prevention and lessons teaching good movement habits in everyday life [10].

Several authors [2, 12, 18, 22, 27, 30] have proved in their studies that appropriately selected and targeted exercise programs and health-oriented compensation exercises can have a positive effect on individual segments of the musculoskeletal system as well as on pain [26]. It is important to start and focus on prevention already in childhood before the primary symptoms of the back pain appear.

Even though the school reform in Slovakia continues at different levels and has different forms, it will be necessary to modify the compulsory physical and sports education syllabi at elementary and secondary schools to incorporate the latest scientific findings. The goal is to make teachers' work more effective and broaden school-aged children's knowledge in terms of their health. The aforementioned findings suggest that school

Table 2. Changes in pain assessment during the experimental stage (V_{3-4}) in experimental group ($n = 12$)

n = 12	1	2	3	4	5	6	7	8	9	10	11	12
$V_{1\ input}$	1	1.5	1	2	1	2	1.5	1	1	1	1.5	2
$V_{2\ output}$	0	0	0	0	0	0	0	0	0	0	0	0.5
$V_{1-2\ difference}$	1	1.5	1	2	1	2	1.5	1	1	1	1.5	1.5
Wilcoxon test						p = 0.002						
Effect size						r = 0.64						

can considerably influence the health of the school-age population from both qualitative and quantitative points of view.

Conclusions

This empirical study helps to extend the knowledge of how to use health-oriented exercise programs, which are focused on the musculoskeletal system segments such as the functional capacity of the spine, the muscle system, and body posture, in physical and sports education lessons. According to our findings, we recommend diversification of the physical and sports education syllabi, which should include lessons focused on the prevention and elimination of musculoskeletal disorders and consider the individual needs of school-aged children. Our study also proves that the diagnosis of changes in this age has a positive effect in terms of prognosis.

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Conflicts of Interest

The authors declare no conflict of interest.

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The influence of high-intensity functional training versus resistance training on the main physical fitness indicators in women aged 25-35 years

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Abstract
Introduction. **Improving the physical fitness and performance of young women depends on the differentiated selection of methods and the amount of the load, the optimal selection of training methods. The aim of the study was to evaluate the influence of 24-week high-intensity functional training (HIFT) program compared to the resistance training (RT) program on health-related physical fitness indicators of women aged 25-35.** Material and Methods. **Thirty-six women (age 30.23 ± 3.5 years) were divided into two groups: experimental (EG; n = 18) – HIFT program, and control group, practicing RT (CG; n = 18). Both programs included exercises with massage rollers, exercises to overcome the weight of their own body, with fitness accessories, three times a week for 24 weeks. Classes in the EG were distinguished by performing 2-3 sets of exercises 15-20 times each (at 85-95% HRmax), separated by 10-30 s to 1 min periods. CG participants trained with an intensity of 60-70% HRmax. Differences in the effectiveness of HIFT and RT were determined by changes from the baseline to the final level in health-related indicators and physical fitness, evaluated by the ALFA-fitness program.** Results. **All scores in the EG and CG, except for the "one-leg stand" ($p = 0.056$) in CG, improved ($p < 0.01$ pre- vs post-training increases for each group). Post-training, waist circumference (69.28 ± 5.00 vs 74.19 ± 6.30 cm, $p = 0.014$), BMI (22.09 ± 1.54 vs 23.27 ± 1.51 kg/m^2, $p = 0.027$), "figure-of-eight run" (7.96 ± 0.61 vs 9.03 ± 1.24 s, $p = 0.002$), "jump-and-reach" (32.33 ± 4.79 vs 26.00 ± 5.25 cm, $p = 0.001$), "2-km walk test" (15.38 ± 0.93 vs 16.86 ± 1.16 m, s, $p = 0.0001$) were better in EG than in CG, respectively.** Conclusions. **RT and HIFT are effective in terms of health and fitness. Compared to RT, HIFT training is more effective in reducing waist circumference, BMI, increasing agility and lower muscle strength, and improving cardiorespiratory fitness.**

KEYWORDS: multifunctional exercises, circular training, working capacity, balance, muscle strength.

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Introduction

An urgent problem of our time is the low motor activity of people, which provokes the occurrence of disorders in the musculoskeletal, cardiovascular, digestive, and respiratory systems, the appearance of excess body weight [2, 13]. A sufficient amount of physical activity for health − recommended for adults − implies a weekly dose of exercise of 150 to 300 min of medium intensity or 75 to 150 min of high intensity [13]. Starting training, women hope to quickly adjust body composition, improve functional abilities and physical fitness, and expand social contacts [10, 12, 13]. The lack of time, insufficient variety, complexity, and monotony of the proposed programs, or fear of injuries can reduce the commitment to systematic training or become the reasons for the termination of training in the first months [12, 15, 16]. Thus, developing an effective fitness program, suitable for physically inactive women, becomes more and more important.

In 2020 fitness trends in Europe the leading is high intensity interval training (HIIT), with body weight training (BWT), functional fitness training (FFT), occupying second, third and fourth places, respectively [5]. Resistance training (RT) is traditionally popular; it helps to maintain or to increase the level of physical and functional capabilities, increase endurance, speed and agility, and is an essential element of recommendations for physical activity [13, 20, 22, 24]. Long-term and systematic RTs contribute to an increase in skeletal muscle strength and mass, walking speed, and improved dynamic balance among women of different ages [1, 17]. However, along with this, comparatively quick adaptation to the nature of the same type of repetitive exercises in the traditional pattern is noted, which can slow down progress in achieving goals, cause boredom, and reduce motivation to continue training [15, 16]. Determining a way to increase functional and physical fitness that would not have the disadvantages of traditional training protocols and at the same time provide the desired health benefits in less time is relevant.

Recent studies confirm that high intensity functional training (HIFT), combining aerobic and power loads, has a positive effect on health, increases interest in physical activity, due to the high emotionality and attractiveness of both the exercises themselves and new types of equipment, it has a similar or superior comparison with RT efficiency [3, 7, 8, 15]. Several variations of HIFT programs, based on bodyweight training, functional fitness training, high-intensity circular training, high-intensity power training, CrossFit®, Tabata, SuperSlow and others, are universal and integrative, characterized by compliance with the principles of HIIT and FFT, include exercises for various joints and muscle groups using bodyweight and various fitness accessories [8, 11, 16, 20, 25]. In a recent in-depth review, Feito et al. [12] show the compelling benefits of using HIFT programs for different groups of people, describe the main differences in HIFT and HIIT methodologies that provide important differences in physiological responses and adaptations.

Having the advantages of traditional RT and HIIT, HIFT programs make it possible to individualize the load as much as possible and focus on improving general physical fitness, including cardiorespiratory fitness, endurance, strength, flexibility, speed, coordination, agility, balance and is perceived by participants as time-efficient and exciting training [16, 19, 20, 21, 25, 28]. HIFT helps to improve performance in everyday functions, provides body composition correction, and has a potential osteogenic effect, in less time than RT [8, 12]. HIFT mode is widely used in the training process of athletes, contributing to the improvement of neuromuscular status, anaerobic power, heart rate restoration, and improves the structure and function of peripheral vessels [28, 29]. Recent, relatively short-term (8-16 weeks) studies show the effectiveness of various HIFT program options, such as multimodal high-intensity interval training, high-intensity power training, CrossFit, CrossFit Teens™ to improve health and fitness levels of different groups of people, increase the popularity of these programs [7, 11, 25]. For example, after 8 weeks of HIFT training, previously physically inactive adults showed improvements in VO_2max, body composition, muscle strength and endurance of the upper and lower body, and flexibility [6]. In longer research (6 months), an assessment of changes in key physical fitness indicators of young women practicing HIFT also showed significant and positive changes in flexibility, muscle strength, and muscle endurance [10]. However, only a few studies attempted to compare RT and HIFT [24, 26, 28]. The advantage of short-term (4-8 weeks) HIFT programs over traditional RTs have been identified in terms of strength, muscle endurance, flexibility, and aerobic abilities for male and female college students [19, 24]. Sobrero et al. [26], comparing the effectiveness of 6-week HIFT and traditional circular training, found that the HIFT program provided better results in terms of body composition and similar improvements in muscle strength and performance of recreationally active women. However, we note that most of these studies were conducted in the early stages of adaptation to training loads and focused on assessing individual indicators of physical fitness, for example, strength or cardiorespiratory fitness [6, 25]. There is very little evidence of optimal ways to implement HIFT to improve the indicators related to health and physical fitness in the long term, so we compared the effectiveness of HIFT and traditional RT programs. We hypothesized that (a) after the introduction of HIFT, there will be an improvement in body composition, cardiorespiratory fitness, muscle strength of the upper and lower parts of the body, muscle endurance of the upper body, balance, agility, and (b) that this training will demonstrate higher efficiency in comparison to the RT group. Thus, the aim of the study was to evaluate the impact of the 24-week HIFT program compared to the RT program on physical fitness indicators related to health among women aged 25-35.

Material and Methods

Participants. The randomized controlled trial was performed in 36 young, non-obese (BMI <30 kg/m^2), healthy women (without chronic diseases), willing to do fitness (Table 1). The participants were on average 29.72 ± ± 3.23 years old, their height was 169.06 ± 3.54 cm, and their mean body weight was 70.5 ± 5.9 kg. Participants were randomly assigned either to the experimental (EG; n = 18) or control (CG; n = 18) group. There were no significant differences between the studied groups. All participating women were informed about the procedures and the main purpose of this study and gave their written informed consent.

Table 1. Baseline characteristics of young women participating in the research assigned to in experimental (EG; n = 18) and control (CG; n = 18) groups

Group	Age (years)		Body weight (kg)		Body height (cm)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
EG	29.97	3.53	70.38	6.31	169.67	4.39
CG	29.46	2.97	70.63	5.64	168.44	2.41

Note: $\bar{x}$– arithmetic mean, SD – standard deviation

Organization of research. During the 24-week research, workouts were conducted three times per week (Monday, Wednesday, and Friday) in both groups (72 workouts). Each training session, in both groups, consisted of the preparatory, main and final part, and lasted 50 min. Our experimental program was developed by one of the authors of the study who conducted the training sessions. In both training programs, exercises of various intensity with bodyweight or different weights were used to develop endurance, strength, balance, and flexibility. The research program included three stages: 1) preparatory stage (1-4 weeks), the task of which was to prepare the participating women for the loads during the main stage, master the basic elements and comprehensive development of physical qualities, and develop a steady interest in physical exercises; 2) main stage (5-12 weeks) aimed at an in-depth study and improvement of the technique of performed physical exercises and achieving a higher level of physical fitness; 3) supporting stage (12-24 weeks) aimed to maintain and further improve physical fitness and health-related indicators.

Each participant used a Polar® heart rate monitor to measure heart rate during exercise and recovery. The calculation of the intensity was carried out according to the Karvonen formula (Target Heart Rate = [(max HR – resting HR) × % Intensity] + resting HR) [18]. The intensity of the exercises, according to the individually calculated training heart rate, was adjusted at the end of each stage of training, which made it possible to control the intensity levels within the desired ranges, ensuring that women of both groups performed exercises with a given intensity.

In the main part of the training (up to 30 min), the EG performed exercises aimed at developing the strength of the muscles of the arms and chest, back, legs, and abdominals. The exercises were performed 8-12 times (85-95% HRmax), with 10-60 s (50% HRmax) rest between each exercise. In the first 4 weeks, we used exercises with body weight and intensity of 75-85% HRmax. It was allowed to replace exercises by lighter ones (pull-ups on a low crossbar, knee-bending arms, etc.). At 1, 4, 7, 10 training sessions, exercises were carried to strengthen triceps, back muscles, deltas, and abs. Exercises for strengthening the arm, chest, and abdominal muscles were performed during 2, 5, 8, 11 sessions. In the 3rd, 6th, and 9th training sessions, exercises were performed to strengthen the muscles of the legs, chest, back and abdominals, using a circular training method. The exercise complex of the circular training consisted of seven exercises (the number of reps 15 times, the rest time 10 s), which were performed one after another. For example, 1st station: pull-ups on a low crossbar; 2nd station: reverse hyperextension on the bench; 3rd station: kettlebell swing, one weight, 6 kg; 4th station: handstand push-up; 5th station: dumbbell lateral raise; 6th station: box jump; 7th station: reverse crunch. When seven exercises were completed, a period of rest (1-2 min) began. After this, two following circles were performed. At the 12th lesson, a set of stretching exercises was carried out (runner's lunge with quad stretch, pigeon stretch, backstretch bridge, backstretch, quad stretch walk, reverse hip skip, carioca quickstep, and foam roll), each exercise took 45-60 s, and the rest time was 10-15 s. Over the next 5-24 weeks, EG women performed complexes containing multimodal, plyometric exercises, and exercises with external resistance (dumbbells, shock absorbers, body bars). With an increase in the level of physical fitness, the intensity of the exercise and the complexity of the exercises was increased by integrating various elements into one exercise, using fitballs, medicine balls, and TRX loops.

CG women trained according to the RT program (60--70% HRmax, individually determined according to Karvonen's formula), which was based on a linear progression of loads: women performed 6-8 exercises (basic, classical power and isolated), with absolute precision and maximum amplitude, trying not to deviate from a given trajectory of movement, working out muscle groups: arm and chest muscles (barbell biceps curl, hammer curl, decline triceps extensions, standing calf (heel) raise, inclined dumbbell bench press, flat dumbbell fly, wrist extension), backs (bent-over row, one-arm dumbbell row, seated pulley row, upright row), legs (leg press, lunges, standing leg curls, leg extensions), press (bent-knee sit-up, abdominal crunch, physioball back extension). In the final phase of the movement, muscle contraction was held for 2-3 s. When returning to the starting position in an eccentric mode, the movement was performed smoothly, without jerking. The exercises were carried out in the order recommended by ACSM, namely, for optimal warming up and increasing the efficiency of subsequent exercises, large muscle groups were worked out first, then smaller muscle groups [13]. CG women performed 2-4 sets of 8-12 repetitions, with 60-90 s rest between multiple sets. Progression was carried out in two ways: method I – by repetitions, when the weight of the weights and the number of repetitions remained the same, and method II – progression by repetitions, when the weights and approaches remained the same, and the number of repetitions increased [13]. Weekly exercise options, as they adapt, every one to two months, changed. Option I: training of the large or small muscle antagonists. On Monday, exercises were performed for the large muscles of the agonists: the chest and back, as well as for the rectus abdominis. On Wednesday, exercises for small muscle groups: deltoid, biceps, and triceps muscles of the shoulder (antagonists), as well as lower legs and rectus abdominis. Large muscle groups were worked out on Friday: exercises for the quadriceps and biceps of the thighs (antagonists), gluteus and adductors, as well as the rectus abdominis muscle. Option II: training of the flexors or extensors. Monday: flexor muscles (biceps of the shoulder, biceps of the thighs, rectus abdominis, etc.). Wednesday: extensor muscles (quadriceps femoris, triceps brachii, extensors, etc.). Friday: training was carried out according to the program of Monday. Option III: training the muscles of the upper or lower torso. Monday: muscles of the thorax, back, biceps and triceps muscles of the shoulder, deltoid muscles and rectus abdominis muscle. On Wednesday, the muscles of the legs, buttocks, legs, and rectus abdominis muscle. On Friday, the workout was carried according to Monday's program.

The final part, among women of both groups, lasted 8-10 min (40-50% of HRmax) and contained exercises for the development of flexibility and relaxation of muscles such as: hanging on the crossbar, longitudinal and transverse splits, and their auxiliary exercises, a bridge, exercises on a massage roller.

Testing procedures. To measure and evaluate the health-related components of fitness, at the beginning and the end of the study, all participants of the experiment were tested using the ALPHA-FIT (Assessment of Physical Activity and Physical Fitness) test pack for adults aged 18-69. Testing was carried out in strict accordance with the recommendations described in detail in the manual. Before testing, warm-up or stretching exercises were not performed for participants [27]. Following indicators were registered: body composition (waist circumference, BMI); motor fitness (one-leg stand, figure-of-eight run); musculoskeletal fitness (shoulder-neck mobility, hand grip, jump-and-reach, modified push-up, dynamic sit-up); cardiorespiratory fitness ("2-km walk test") [27]. Bodyweight (kg) and height (m) were measured to calculate BMI (kg/m^2), bodyweight was measured to the nearest 0.01 kg using electronic scales Seca 703 (Seca North America, Chino, CA, USA), and height was measured to the nearest 0.5 cm using a stadiometer Seca 264 (Seca North America, Chino, CA, USA).

Statistical analysis

All statistical analyzes were carried out with SPSS version 22.00 software (IBM SPSS, Armonk, NY, USA). All data are presented as mean ± standard deviation of the mean (SD). The data were checked for normal distribution using the Kolmogorov–Smirnov test, the achieved significance level was more than 0.05. One-way analysis of variance (ANOVA) was used to compare the average values between the results in independent groups, namely, preliminary testing in the EG and CG, and the results of post-testing in the EG and CG. To compare the average values in dependent samples, i.e. between the results in the EG (pre- and post-training) and comparison of the average values between the results in the CG (pre- and post-training), we used one-way analysis of variance for repeated measurements (Repeated Measures ANOVA). Measures of the effect size (ES) for differences were calculated by dividing the mean difference by the standard deviation (SD) of the pre-training measurement. The magnitude of the ES was classified according to the following criteria: $0.2 < d < 0.5$ was considered "small", $0.5 < d < 0.8$ represented "medium", and $d > 0.8$ constituted "large" [9]. Differences were considered to be reliable at a significance level of $p < 0.05$.

Results

Prior to the experiment, no significant differences were found between the groups ($p \geq 0.05$) in body composition, cardiorespiratory fitness, muscle strength and endurance of the upper and lower body parts, the level of agility, and development of the stability functions. This signifies the homogeneity of the groups before the research.

The first hypothesis was fully confirmed, all assessments in the EG showed an improvement from pre-testing to post-testing ($p < 0.0001$). Most significantly, in this group, improved short-term endurance capacity of the upper extremity extensor muscles and the ability to

Table 2. Health-related fitness test scores before (pre-test) and after 24 weeks of training (post-test) in experimental (EG; n = 18) and control (CG; n = 18) groups

Measurable indicators	Groups	Pre-test $\bar{x}$ (±SD)	Post-test $\bar{x}$ (±SD)	P	ES	Δ%
Waist circumference (cm)	EG	74.46(6.6)	69.28(5.00)*†	0.0001	0.88	–6.95
	CG	78.23(7.12)	74.19(6.30)*	0.0001	0.60	–5.11
	p	0.110	0.014			
BMI (kg/m^2)	EG	24.82(2.12)	22.09(1.54)*†	0.0001	1.47	–10.99
	CG	24.78(2.13)	23.27(1.51)*	0.0001	0.81	–6.09
	p	0.947	0.027			
One-leg stand (s)	EG	50.33(21.92)	57.61(22.60)*	0.0001	0.33	14.46
	CG	45.94(24.90)	46.91(25.11)	0.0560	0.04	2.11
	p	0.578	0.188			
Figure-of-eight run (s)	EG	8.83(1.02)	7.96(0.61)*†	0.0001	1.04	–9.85
	CG	9.27(1.33)	9.03(1.24)*	0.0050	0.18	–2.59
	p	0.263	0.002			
Shoulder-neck mobility (points)	EG	7.67(1.61)	8.56(1.34)*	0.0010	0.60	11.60
	CG	6.94(2.41)	8.55(1.38)*	0.0001	0.82	23.19
	p	0.298	0.715			
Hand grip (kg)	EG	39.12(4.57)	42.92(5.23)*	0.0001	0.77	9.71
	CG	38.70(5.72)	40.36(5.76)*	0.0001	0.29	4.28
	p	0.808	0.173			
Jump-and-reach (cm)	EG	27.17(5.47)	32.33(4.79)*†	0.0001	1.00	18.99
	CG	25.22(5.43)	26.00(5.25)*	0.0001	0.15	3.09
	p	0.292	0.001			
Modified push-up (total number)	EG	8.39(2.00)	12.00(2.40)*	0.0001	1.63	43.02
	CG	11.33(2.22)	8.89(2.42)*	0.0001	1.05	21.54
	p	0.940	0.393			
Dynamic sit-up (total number)	EG	12.67(3.50)	16.78(3.70)*	0.0001	1.14	32.43
	CG	13.38(3.64)	16.67(3.71)*	0.0001	0.89	24.58
	p	0.548	0.894			
2-km walk test (m, s)	EG	16.90(1.13)	15.38(0.93)*†	0.0001	1.47	–8.99
	CG	17.08(1.10)	16.86(1.16)	0.0001	0.18	–1.23
	p	0.630	0.0001			

Note: CG – control group, EG – experimental group, ES = Cohen's d effect size, $\bar{x}$ (±SD) = mean ± standard deviation, * $p \leq 0.05$ (between study terms), † $p < 0.05$ (between study groups) stabilize the body. So in the test "modified push-up" the number of repetitions increased by 3.61 ± 0.40 ($F = 270.48$, $df = 1.17$, $p = 0.0001$), and in the test "dynamic sit-up" the number of repetitions increased by 4.11 ± 0.20 ($F = 173.68$, $df = 1.17$, $p = 0.0001$). Agility and muscular power of lower extremities, according to the results in "figure-of-eight run", also improved ($F = 30.86$, $df = 1.17$, $p = 0.0001$). Waist circumference and BMI ($p < 0.0001$) decreased significantly. All test results in CG, except for "one-leg stand" ($F = 4.22$, $df = 1.17$, $p = 0.056$), also showed an improvement from pre-testing to post-testing ($p < 0.05$). The most functional mobility of the shoulder and neck region was significantly improved according to the results of the "shoulder-neck mobility" test ($F = 23.172$, $df = 1.17$, $p = 0.0001$). Table 2 shows a comparison of physical fitness indicators (ALPHA-FIT test) obtained before and after the experiment.

Regarding the second hypothesis, a comparison of the results of the final testing in EG and CG revealed that the HIFT training showed higher efficiency compared to RT in five indicators. Thus, statistically significant differences were found in the indicators of waist circumference ($F = 6.71$, $df = 1.35$, $p = 0.014$), BMI ($F = 5.38$, $df = 1.35$, $p = 0.027$), the level of agility ("figure-of-eight run", $F = 10.75$, $df = 1.35$, $p = 0.002$), the strength of the lower body muscles ("jump-and-reach", $F = 14.31$, $df = 1.35$, $p = 0.001$), and the cardiorespiratory efficiency ("2-km walk test", $F = 17.665$, $df = 1.35$, $p < 0.001$). Both training programs caused similar changes in mobility of the shoulders and neck, handgrip strength, the number of push-ups, and the values of the dynamic squat test.

Discussion

The main finding of this study was that both, HIFT and RT contribute to positive changes in the studied parameters (body composition, motor, and musculoskeletal fitness, cardiorespiratory fitness), which indicates the effectiveness of both programs in general. However, when comparing the two training programs, HIFT caused a greater effect on waist circumference, BMI, agility development, the lower body muscles' strength, and cardiorespiratory fitness. The ability to maintain body balance in difficult postural conditions increased only in the HIFT group.

Body composition. A change in body composition is widely used as an indicator of the effectiveness of the selected training regime. The study found that both training programs are effective in reducing waist circumference (WC) and lowering BMI among healthy, young women. However, HIFT was significantly more effective in reducing these parameters, which corresponds with comparable reductions in subcutaneous adipose tissue reported after 8 weeks of HIFT [11, 12, 26]. Significant efficacy of CrossFit Teens™ training (60 min twice a week) was found in adolescents; among others WC decreased by 3.1 cm ($p < 0.001$), BMI decreased by 1.38 kg/m^2 ($p < 0.001$) [11]. Smith et al. [25] reported that 10-week high-intensity power training programs using "day training" (WOD) contributed to a decrease in BMI by 0.7 ± 0.1 kg/m^2 ($p = 0.01$). However, our data are not consistent with the data of Heinrich et al. [15], Tomljanović et al. [28], who did not find significant changes in WC and BMI in men and women (22-30 years old) after identical, but shorter (5-8 weeks) training programs. These discrepancies can be in great part explained by the shorter duration of interventions, the intensity, and type of exercise, the studied categories of participants (men and women), their number (9-15 people), or the presence or absence of obesity.

Motor fitness. In this study, the ability to maintain body balance in difficult postural conditions, according to the results of the "one-leg stand" test, significantly changed only in EG. Despite that Cosgrove et al. [10] did not find balance improvements after HIFT for young women, there are reports of improved balance after RT among older women [17]. The significant changes in the results of the "figure-of-eight run" test (specifying the level of agility development) indicate a greater influence of HIFT on the efficiency of neuromuscular coordination. Our data are consistent with the results of Barranco-Ruiz and Villa-González [4], which reported that 16 weeks of Zumba Fitness® training, supplemented with bodyweight strengthening exercises, significantly improved the results of "figure-of-eight run". Also, Rogers et al. [22] reported a 9.8% agility improvement after RT.

Musculoskeletal fitness. We assessed the posture and functional mobility of the shoulder and neck region, since among adults sometimes pain and restrictions in the sagittal mobility of the lower cervical and upper thoracic spine may be observed [14, 23]. Both types of training increased the range of motion of the lower cervical and upper thoracic spine. Moreover, in CG women, the improvement in this indicator was more significant. Probably, performing a variety of exercises in which the short rotator muscles were involved, and exercises with a wide range of motion in the shoulder joints, cervical and lumbar spine significantly improved this ability. Although at the time of publication, we have found no other studies examining the effect of HIFT on posture and functional mobility of the shoulder and neck region based on the results of the "shoulder-neck mobility", our results are comparable with the data of Barranco-Ruiz and Villa-González [4], which revealed an increase in the mobility of the neck and shoulders by 2.123 ± 0.47 points ($p = 0.0001$; Cohen's $d = 0.60$). Our results indirectly correlate also with a 10-20% increase in isometric neck strength and an improvement in the neck range of motion among adults with chronic neck pain after RT [14]. We believe that a scrupulous study of the effect of HIFT on the functional mobility of the shoulder and neck region is required.

In the present study, an improvement in hand muscle strength, which is necessary for many daily functions, was noted in both the EG and CG, yet the greater difference was caused by HIFT. The greater effect in improving hands muscle strength among women from EG can be explained by the 25% higher intensity of that strength training. However, that considerable difference between groups in the intensity of the training was not large enough to cause a significant difference in muscle strength' increases between groups. The increments in hands muscle strength are similar in the present study to those found in young women practicing the modified Zumba Fitness program ($p < 0.05$) [4] and in older women after the strength training (16.31%; $p < 0.01$) [21].

The muscle strength of the lower body improved only after HIFT training. The most probably the performance of plyometric exercises that effectively influenced the "jump-and-reach" test result in EG. Buckley et al. [7] reported an increase in muscle strength (squat, deadlift, and overhead press strength) after high-intensity multimodal exercise ($p < 0.01$). Sobrero et al. [26] noted an improvement in the "vertical jump" test after 10 weeks of HIFT ($p = 0.029$). However, Ahtiainen et al. [1] also reported that after 6 months of RT training, women under the age of 45 years, had a maximal bilateral concentric strength of the hip and knee extensors, and plantar flexors increased by 26.7 ± 13.9%.

Both indicators of muscular endurance of the body (the number of repetitions performed during the "modified push-up" and "dynamic sit-up" tests) show a significant improvement among women in the EG and CG groups. Probably, the combination of gymnastic and weightlifting exercises in the HIFT program contributed to a greater increase in the efficiency of movements. Our results are similar to improved muscle endurance ($p < 0.0001$) and upper body strength ($p = 0.007$) after HIFT and traditional circular training [26], and 18.6% increase in bench press and 22.7% increase in leg press after HIFT showed by Brisebois et al. [6]. Improvements in both of these assessments are expected since each group performed the exercises using both their body weight and fitness accessories [3, 12, 13]. Sartor [24] found that after 8 weeks of both HIFT and traditional strength training, participants significantly improved muscle endurance, without significant differences between groups. In this case, it can be argued that both of these methods are important and effective in increasing the muscular endurance of the trunk.

Cardiorespiratory fitness. A significant decrease of 8.99% in the time of the "2-km walk test" was noted among women from the EG group, compared to 1.23% in women from CG. Possibly, aerobic exercise included in the high-intensity functional training led to a greater adaptation of the oxygen delivery system and improved its use by active muscles. Furthermore, the active rest between exercises also helped to improve muscle metabolism. In our opinion, aerobic exercises aimed at developing general endurance were not sufficiently included in the exercise complexes used in the control group. Our findings can only be compared to other studies indirectly, and with caution, since most of the changes in cardiorespiratory fitness were judged by changes in VO_2max level measured using laboratory tests, while in our study we used a field test. We assume that the improvement in cardiorespiratory fitness is comparable to previous studies, which reported significant improvements in VO_2max from 7% to 11.8% after 4-10 weeks of training [6, 7, 25]. For example, after a 6-week multimodal HIIT, a 7% increase in VO_2max was found [7], and participation in a 4-week Tabata training resulted in a 7-8% increase in VO_2max ($p < 0.05$) in young women [20]. After 10 weeks of Crossfit-based high-intensity power training, the relative VO_2max improved by 11.8% [25]. Brisebois et al. [6] reported that among previously inactive men and women, after 8 weeks of HIFT, the absolute VO_2max increased by 6.3% ($p = 0.003$; Cohen's $d = 0.23$), and relative VO_2max by 5.5% ($p = 0.003$; Cohen's $d = 0.21$). Cosgrove et al. [10] found that the time to cover a distance of 1.5 miles was significantly shorter in the less experienced group (0-6 months) compared to the more experienced group (7+ months). In contrast, Sobrero et al. [26] showed that 6 weeks of HIFT training did not significantly affect the cardiorespiratory fitness of women. Also, Kim et al. [19] received no evidence of a positive effect of 4 weeks of either RT or SuperSlow resistance training on aerobic abilities of young women.

A limitation of this study is that one of the researchers was involved in the design and implementation of the HIFT program. Besides, this study was limited by sample size. Since there are many different HIFT and RT training programs, the comparison of results obtained by us does not guarantee that the HIFT applied in this study is superior to other training programs.

Conclusions

As far as we know, this was the first study that compared the effectiveness of 24 weeks of HIFT and RT concerning the health and physical fitness of young women. Our results could be significant for public health as they show that both programs contribute to positive changes in the studied indicators. However, we identified differences in effectiveness that depend on the type of program. The obtained results allow us to consider HIFT as a more effective and alternative choice to RT to improve body posture, working capacity, health indicators, and promote a long-term commitment to physical activity. These results may also be of interest to researchers and fitness trainers and can be used to develop training programs for women who begin to do fitness to improve their well-being and overall health.

Conflicts of Interest

The authors declare no conflict of interest.

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The use of Yo-Yo intermittent recovery test level 1 for the estimation of maximal oxygen uptake in youth elite soccer players

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Abstract

Introduction. **Researchers have proposed some equations for the estimation of VO_2max in adults with the use of the total distance or the maximum velocity of the Yo-Yo test. However, the use of these equations for estimating the VO_2max in children may include mistakes. Their physiological adaptations to incremental exercise are different than in adults.** Aim of Study. **The purpose of this study was to investigate the relationship between a) the predicted VO_2max (by a published equation) with the VO_2max measured in the laboratory and b) the velocity at the last stage of Yo-Yo IR1 (YYIR1) with the vVO_2max measured in the laboratory in elite youth soccer players (U17).** Material and Methods. **Twenty-seven soccer players completed a laboratory treadmill test (LTT) and the YYIR1 which were conducted in random order. Their VO_2max was measured during LTT and had been predicted by the results of the YYIR1 test from a published equation.** Results. **The values of VO_2max in LTT and YYIR1 were different ($t = -7.652$, $p < 0.001$) (58.9 ± ± 5.3 and 50.8 ± 2.7 ml/kg/min, respectively). There were no differences between the measured values of vVO_2max in LTT and YYIR1 ($t = 1.652$, $p = 0.11$). Also, no differences were observed in HRmax values in the two tests ($t = -0.185$, $p = 0.854$). The equation derived from the results of the present study did not have prediction power ($r = 0.11$, $r^2 = 0.012$).** Conclusions. **The VO_2max which was predicted by the published equation from the performance of YYIR1 was different from VO_2max was measured in the laboratory in elite youth male soccer players (U17). However, YYIR1 could be used for measuring HRmax and VO_2max velocity.**

KEYWORDS: aerobic capacity, football, prediction, maximal oxygen consumption.

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Introduction

Soccer is an intermittent-type of sport that incorporates actions with low and high intensity and duration. The development and use of technology help trainers and scientists to study extensively the physical demands of soccer [25]. In elite youth soccer, distances around 9 km are covered by players, and approximately 10% of this distance is covered in high velocity [2, 9]. Additionally, soccer players perform many other activities in a match, such as accelerations, decelerations, jumps, changes of direction, and others [9]. All of the above actions activate aerobic and anaerobic metabolism which are crucial for soccer players' performance [20].

The aerobic capacity may be assessed with the measure of maximum oxygen uptake (VO_2max), which refers to the maximal ability of the body to use oxygen during maximal effort. The gold standard for assessing VO_2max consists of maximal laboratory tests using a treadmill [12]. Some other indices which were measured during laboratory testing are velocity at which VO_2max occurred (vVO_2max) and the velocity at which RER 1 occurred (vRER1). All of the above indexes can be used for the design and evaluation of aerobic training. Previous researchers have mentioned that vVO_2max is a better indicator of performance than VO_2max because it combines both VO_2max and running economy [14]. As a performance indicator vVO_2max can explain inter-individual differences in performance [17] and can be used to determine optimal training intensity [7]. More specifically if an athlete increases his vVO_2max through training he will also improve his running performance [17].

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 like that of a soccer team. All the reasons mentioned above lead to developing different field tests for VO_2max, vVO_2max and other indexes estimation [4, 23]. Those tests are less accurate but the trainer can measure a lot of players in less time, using much less equipment.

One of the field tests that is commonly used in soccer is the Yo-Yo intermittent recovery test which was devised and developed based on another test, the maximal multistage 20 m shuttle run test (20-MST) [4] which was described for the first time by Léger and Lambert (1982) [23]. Many researchers have studied the correlation between the performance in the Yo-Yo test and VO_2max and some of them have mentioned weak correlations [3, 11] while others moderate to strong correlations [19]. Additionally, previous studies showed that the total distances covered in a match by players and the distances in different velocities are correlated to the players' performance in the Yo-Yo test [10].

Researchers have proposed a couple of equations for the estimation of VO_2max in adults [4] with the use of the total distance or the maximum velocity of the Yo-Yo test. However, the use of these equations for estimating the VO_2max in children may include mistakes. Their physiological adaptations to incremental exercise are different than in adults [27]. Also, youths experience a faster recovery after maximal intermittent bouts of exercise which can affect the performance in this kind of exercise [24]. For the reasons above it is hypothesized that age could be a crucial factor inVO_2max estimation via Yo-Yo test performance.

Aim of Study

The purpose of this study was to investigate a) the relationship between the predicted VO_2max from the results of Yo-Yo IR1 (by the equation proposed by Bangsbo et al., 2008) [4] with the VO_2max measured in the laboratory, and b) the relationship between the velocity at the last stage of Yo-Yo IR1 (YYIR1) and vVO_2max measured in the laboratory. Additionally, the third aim of this study was to produce regression equations enabling the use of YYIR1 distance to predict VO_2max, in elite youth soccer players, aged 15-17 years.

Material and Methods

Subjects

Twenty-seven elite youth soccer players (16.5 ± 1.2 y; 1.73 ± 0.04 m; 68.1 ± 3.4 kg; mean ± SD) participated in the study. Furthermore, all participants and their parents were informed about the potential risks and benefits of the study, and a written consent form was signed by the parents. The local Institutional Review Board approved the study, in the spirit of the Helsinki Declaration.

Procedure

All players completed two tests (an incremental laboratory treadmill test (LTT) and the YYIR1 test) in random order during a 10-day period. The study was conducted before the in-season period. Players' VO_2max was measured during LTT and was estimated from the results of YYIR1. Furthermore, testing was performed under the same conditions and the players were instructed to avoid intense exercise during the 24 hours before the tests.

During their first visit to the laboratory, all players were familiarized with the procedures for the treadmill test and the YYIR1 test. Also, they had their body mass, height, and percentage of body fat measured. During the next two visits (almost 7 days apart), the participants performed the aerobic tests. In the beginning, the soccer players performed a 10-minute warm-up, and at the end a 10-minute cool-down. During the 10 days of the study, the players participated in five training sessions. Additionally, all participants consumed water ad libitum to ensure proper hydration during training and testing.

Anthropometric and assessment of maturity status

Body mass was measured to the nearest 0.1 kg using an electronic digital scale with the participants in their underclothes and 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 using a specific caliper (Lafayette, Ins. Co., Indiana) on the right side of the body. The body fat was estimated using the equation of Siri (1956) [28].

Laboratory VO_2max and vVO_2max assessment

VO_2max of soccer players was assessed in the morning. The room temperature was around 22°C and the relative humidity was approximately 50%. The cardiorespiratory VO_2max test was performed on a motorized treadmill (Pulsar, h/p/Cosmos, Nussdorf-Traunstein, Germany). The first stages of the protocol had similar velocities with YYIR1. More specifically the initial grade was 0% and the first stage had a speed of 10 $km \cdot h^{-1}$ for 30 seconds. For the next three stages, the speed was increased every 30 seconds by 1 $km \cdot h^{-1}$. The fifth stages' velocity was 14 $km \cdot h^{-1}$ for 1 minute and was gradually increased in the next stages every 2 minutes until exhaustion. After the final stage, a cool-down session took place for 5 min, at 4 $km \cdot h^{-1}$, and 0% grade. VO_2max values and cardiorespiratory indices were measured via a breath-by-breath automated pulmonary-metabolic gas exchange system (Oxycon Pro, Jaeger, Wurzburg, Germany). Furthermore, prior to all tests, O_2 and CO_2 analyzers were calibrated using certified gas concentrations and the mass flow sensor was automatically calibrated against a 2.0 L calibration syringe. The highest VO_2 value recorded at the maximal exercise intensity, after achieving the stabilization of VO_2 for at least 5 measurements (steady-state), was considered VO_2max. During the testing, also other cardiorespiratory parameters were recorded: heart-rate (HR), maximal HR, and respiratory exchange ratio (RER). The heart rate (HR) was recorded every 5 s throughout the exercise tests using short-range telemetry (Polar H2, Polar Electro Oy, Kempele, Finland).

VO_2max was assumed when at least one out of the four following criteria, was met: a) HR during the last minute exceeded 95% of the expected maximal HR predicted using formula 220-age; b) leveling off (plateau) of VO_2max despite the increase in treadmill grade; c) a respiratory gas exchange ratio (VCO_2/VO_2) equal to or higher than 1.1 was reached; d) the subject was no longer able to continue running despite verbal encouragement.

The lowest running speed that elicits a VO_2 equivalent to VO_2max during the treadmill test was defined as vVO_2max [6]. If the final exercise workload was not completed for 120 s but VO_2 continued to increase then vVO_2max was determined from the following equation [21] (Equation 1):

$$vVO_2\text{max} = \text{last workload completed in 120 s} = \\ = [(\text{time of the uncompleted work load}/120) \times 1]$$

Yo-Yo intermitted recovery test level 1

The YYIR1 consisted of 2 × 20 m intervals of running interspersed by regular short rest periods (10 s). Furthermore, signals were given by a CD-ROM to control the speed. The player run 20 m forward and he adjusted his speed, so to reach the 20 m marker exactly at the time of the signal. Additionally, a turn was made at the 20 m marker and the player run back to the starting marker, which was to be reached at the time of the next signal. Then the player had a 10 s break for running slowly around the third marker which was placed 5 m behind him. He had to wait at the marker until the next signal. The course was repeated until the player failed to complete the shuttle run two times in a row. The first time, when the start marker was not reached a warning was given ('yellow card'), the second one the test was terminated ('red card'). The last running interval that a player had completed before being excluded from the test was noted, and the test result was expressed as the total running distance covered in the test [11]. The YYIR1 also started at a speed of 10 km/h. Furthermore, in the next 2 speed levels, the speed was increased by 2 and 1 km/h, respectively. Thereafter, the speed was increased by 0.5 km/h at every speed level. The vYo-Yo IR1 was sustained during the last completed 40 m.

VO_2max prediction

Players' VO_2max was predicted from their distance covered in the YYIR1 using the equation recommended by Bangsbo et al. [4] (Equation 2):

$$VO_2\text{max prediction (ml/kg/min)} = \\ = \text{Yo-Yo IR1 distance (m)} \times 0.0084 + 36.4$$

Statistical analysis

Data are presented as means ± SD. Additionally, data normality was verified with the 1-sample Kolmogorov--Smirnov test; therefore, a nonparametric test was not necessary. The scores from the treadmill test and the YYIR1 were compared using a paired T-test. Pearson coefficient was used to verify the correlation between factors of the treadmill test and YYIR1. The relationship between YYIR1 performance and VO_2max was tested using linear regression analysis. The level of significance was set at $p < 0.05$. SPSS version18.0 was used for all analyses (SPSS Inc., Chicago, IL, USA).

Results

The analysis of the data revealed differences between VO_2max was measured in the laboratory and VO_2max predicted with the use of Equation 1 ($t = -7.652$, $p < 0.001$) (58.9 ± 5.3 ml/kg/min and 50.8 ± ± 2.7 ml/kg/min, respectively). Also, differences were observed in the total duration of the tests (488 ± 89 s for LTT and 852 ± 152 s for YYIR1; $t = 13.075$, $p < 0.001$). There were no differences between the measured values of vVO_2max during LTT and during YYIR1 (4.61 ± ± 0.29 m/s and 4.51 ± 0.14 m/s respectively; $t = 1.652$, $p = 0.11$). Also, no differences were observed in HRmax measured during both tests (193 ± 7.6 beats/min and 193 ± 7.7 beats/min for LTT and YYIR1, respectively; $t = -0.185$, $p = 0.854$) (Table 1).

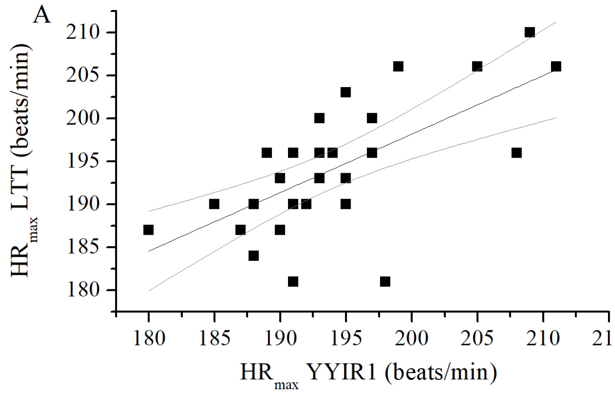
Table 1. Comparison of test results between YYIR1 and LTT (mean ± SD)

Test	Duration (sec)	Maximal velocity (km/h)	HRmax (beats/min)	$\dot{V}o_2max$ (ml/kg/min)	
				Estimated	Measured
YYIR1	852 ± 152	4.5 ± 0.1	193.7 ± 7.6	50.8 ± 2.7	--------
LTT	488 ± 89	4.6 ± 0.3	193.7 ± 7.7	---------	58.9 ± 5.3

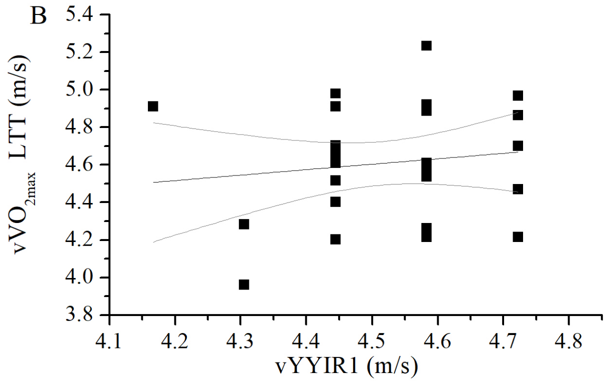
Note: YYIR1 – Yo-Yo intermittent recovery test level 1, LTT – maximal laboratory treadmill test, HRmax – maximal heart rate

The correlation coefficient between the two tests (LTT and YYIR1) for HR and velocity were $r = 0.68$ ($p < 0.001$) and $r = 0.13$ ($p = 0.503$), respectively (Figure 1).

A



B

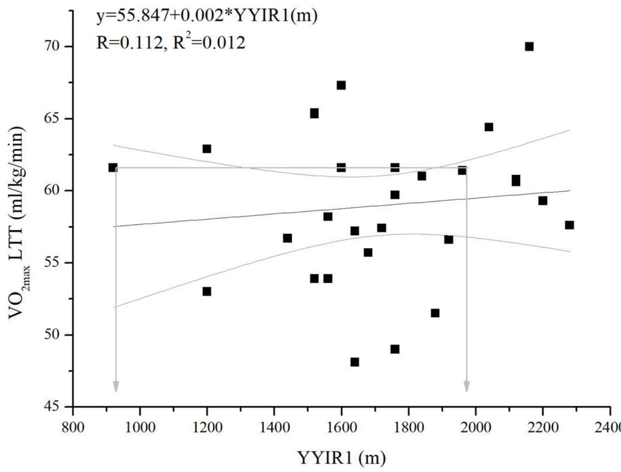


Note: HRmax – maximal heart rate, YYIR1 – Yo-Yo intermittent recovery test level 1, LTT – maximal laboratory treadmill test, vVO_2max – velocity at VO_2max, vYYIR1 – velocity at the last complete level of Yo-Yo intermittent recovery test level 1

Figure 1. Correlation and confidence intervals (95%) between the results of YYIR1 and LTT in A: maximal heart rate and B: maximal running velocity

The equation for the prediction of VO_2max (Equation 3) was based on the linear regression analysis ($r = 0.11$, $r^2 = 0.012$) (Figure 2):

$$VO_2max = 55.847 + 0.002 \times \text{Yo-Yo IR1 (distance m)}$$



Note: The grey lines indicate the variation of the distance covered in YYIR1 (920-1,960 m) for a given VO_2max of ~61.5 ml/kg/min; LTT – laboratory treadmill test, YYIR1 – Yo-Yo intermittent recovery test level 1

Figure 2. Correlation between the VO_2max obtained during LTT and the distance covered in the YYIR1

Discussion

One of the primary aims of this study was to investigate the validity of predicting VO_2max of elite youth male soccer players based on the performance of the YYIR1 test. The results indicated that there were differences between the direct measure of VO_2max and the indirect estimation of VO_2max with the use of Equation 2. The results above confirmed that, in elite male youth soccer players, we can not compare the VO_2max predicted with the use of Equation 2 with the VO_2max measured in the laboratory. Also, the VO_2max measured by the YYIR1 compared to the LTT was underestimated by 15.9%.

Additionally, the results of the present study indicate a non-significant relationship between YYIR1 performance (distance) and LTT VO_2max ($r = 0.112$, $p = 0.572$). To our knowledge, only one study has investigated the relationship between YYIR1 and VO_2max in elite youth male soccer players [18] and showed moderate relationships between a VO_2max measurement and distance covered in the YYIR1. However, many studies were performed in adult soccer players [19] and they mentioned from weak to strong correlations between YYIR1 distance and VO_2max (measured during LTT).

The YYIR1 is a field test which for every 40 m has a 10 s active recovery. This is its main difference from LTT which is a continuous test. Another difference is the energy cost and the ability for maintaining the economy in constant changes of direction in the YYIR1. This diverse running economy could be a reason for the above differences or the lack of relationships [11]. Figure 2 shows that players with similar VO_2max (61.4--61.6 ml/kg/min) may run different distances in YYIR1 (920-1,960 m).

Additionally, one possible explanation for this difference could be different, than in adults, physiological adaptations of children to incremental exercise [27]. More specifically, youths in comparison to adults 1) in all intensities have a greater oxygen consumption per body weight, 2) have higher levels of ventilation per kilogram at submaximal and maximal speeds, 3) have inferior breathing efficiency, and also 4) they have higher heart rates at all exercise levels [27]. In comparison to adults, youths have limited glycolytic ability during high-intensity exercise, while their aerobic metabolism is higher [22]. Furthermore, the levels of muscle oxidative enzymes are increased in youngsters, and this promotes lipid oxidation in energy production. However, aerobic metabolism cannot supply enough energy for high-intensity movements [1, 16, 26]. Finally, youths have faster recovery after maximal intermittent bouts of exercise [16] which can affect the performance in this kind of exercise [24]. Also, recovery time can influence the contribution of metabolic systems to energy production during the next bout [5]. Based on the faster VO_2 kinetics, the greater muscle oxidative enzyme activity, and the increased recovery potential of youths when compared to adults, it is justified to claim that age could be a crucial factor for VO_2max estimation via Equation 2 and the use of YYIR1 performance.

Previous studies have mentioned that for an accurate VO_2max determination the treadmill protocol duration has to last at least 8 minutes [15]. In our study, the average time of our protocol was ~8 min (Table 1) which covers the above condition. Also, the protocols' speed and duration at each level were similar to the characteristics of the YYIR1 test.

The proposed equation 3 has been derived from the data of our study sample. As it hasn't got a prediction power ($r = 0.11$, $r^2 = 0.012$) it is very needed to find a proper equation for elite youth male soccer players. Therefore, further research with more participants is required in this study area. Previous studies that used continued exercise protocols (20 m shuttle run test, Yo-Yo endurance test) have mentioned better prediction indexes of VO_2max than YYIR1 [11, 23].

The vVO_2max could be used in training and it would be very useful if it could be measured during a field test evaluating many athletes simultaneously. Previous researchers showed that vVO_2max is the lowest exercise intensity that could be used for improving aerobic capacity [13]. Also, the increase of vVO_2max through training improves the running speed which corresponds to a given percentage of VO_2max [17].The results of the present study showed that the vVO_2max obtained on the treadmill and vYYIR1 were similar. More specifically, the mean value of vVO_2max was higher by 2.2% (0.1 m/s) than vYYIR1. Furthermore, previous studies have mentioned that overcoming air resistance during field running implies additional energy expenditure reaching to at least 4% of the total expenditure, as compared to treadmill running [8]. Additionally, the changes in direction in YYIR1 increase the energy cost of running. These factors probably can explain the small difference between the two measured velocities. Moreover, the comparable HRmax, attained by the players in both LTT and the YYIR1, shows that they gave their maximal effort during both tests before reaching voluntary fatigue and that the YYIR1 is suitable to determine HRmax in these subjects.

This study presents some limitations that should be mentioned. Firstly, the number of participants was limited and the generalization of our findings should be made with caution. Secondly, probably the use of a mobile ergospirometer would be more proper to measure the VO_2max during the YYIR1 test.

Conclusions

In conclusion, the level of VO_2max predicted with the use of the equation proposed by Bangsbo et al. from the results of YYIR1 was significantly underestimated compaerd to VO_2max measured in the laboratory in elite youth male soccer players (U17). Additionally, the different physiological adaptations of youths to incremental exercise, compared to adults, could be a crucial factor of VO_2max estimation via YYIR1 performance. Finally, because the equation proposed in the current study did not have a prediction power, there is still a need for future studies to form an equation appropriate for youth athletes.

Conflicts of Interest

The authors declare no conflict of interest.

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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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