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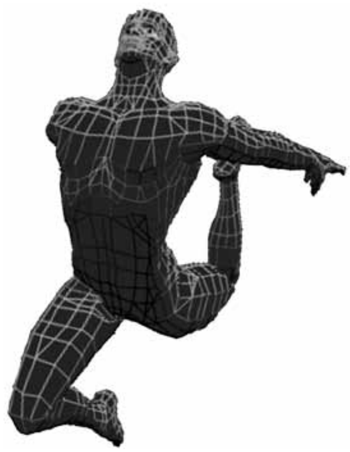

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THE EFFECTS OF MUSCLE STRENGTHENING ON NEURO-MUSCULO--SKELETAL DYNAMICS IN A SQUAT JUMP: A SIMULATION STUDY

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ABSTRACT
Purpose. The aim of this study was to quantitatively investigate the effects of muscle strengthening in a vertical squat jump based on a neuro-musculo-skeletal model and a forward dynamics simulation. **Methods.** During simulation trials, 16 major muscle groups of the lower extremities were gradually strengthened up to 20%. **Results.** Complex yet systematic deviations in body kinematics, kinetics and the neural control pattern were observed as a result of gradual muscle strengthening. **Conclusions.** Based on the generated results it was concluded that: (i) the pattern of kinematical changes depends on which muscles are strengthened, while the magnitude of the changes depends on how much the muscles are strengthened. (ii) Adjustment of muscle coordination, in some cases, can be performed without adjustment of neural control. (iii) The adjustment of neural control is done in an adaptive manner. (iv) Inter-segmental coordination is further altered if a smaller number of muscles are strengthened. (v) The main effect of equally strengthening all the muscles is an increase in joint torque, which is proportional to the increase in muscle strength.

Key words: muscle strengthening, squat jump, simulation, neural control, motion mechanics

Introduction

Previous studies have demonstrated that muscle strengthening has different and complex effects on neuro-musculo-skeletal dynamics in jumping. First, as was demonstrated, was that muscle strengthening is the most effective way in increasing jump performance [1]. It was also shown that strength training can increase the muscle fibre cross-sectional area by as much as 30%, while the peak force of a single fibre can increase by 19% [2]. At the same time, other experimental studies found that after the muscles were strengthened, joint torque increased by 20–30% [3]. Also reported in literature on the subject was that jump height increased by 10–21% when the muscles were strengthened [4, 5]. Finally, it was observed that even after the muscles were significantly strengthened, the jump was performed in a manner similar to the one before strengthening [6].

Although these experimental studies have reported a large number of very important effects of muscle strengthening on neuro-musculo-skeletal dynamics, up to now there have been few studies elucidating how muscle strengthening affects the entire dynamics of the neuro-musculo-skeletal system. The reason for the lack of such quantitative explanation is that in order to find these causes it is necessary to study the mutual and complex relationships among the mechanics of body segmental motion, neural control and patterns of muscle exertion after muscle strengthening. However, either for ethical or technical reasons, it is very difficult to collect all the needed data experimentally in vivo.

Even if it is difficult to study neuro-musculo-skeletal dynamics through experimental procedures, simulation studies can be used as a powerful tool in studying the dynamics of the neuro-musculo-skeletal system. As such, simulation studies have been used in several analyses, including this one. In previous simulation studies it was found that adjusting neural control to strengthen muscles [6] is a very important factor in increasing jump height. It was also found that the larger amount of muscles that were strengthened together, the more neural adaptation is needed [7]. It was shown that the strengthening of knee extensors is the most effective way to increase performance during a vertical squat jump [1], and, when all muscles are strengthened together equally, the increase in jump height is approximately proportional to the increase in muscle strength [7].

Therefore, the aim of this study was to investigate the specific effects of muscle strengthening on the complex relationships between neural control, muscle exertion patterns and the resulting motion dynamics. An understanding of such relationships is not only important in sport biomechanics, but it can also help in the design of rehabilitation strategies and to better understand the human neuro-musculo-skeletal system [8].

Material and methods

Due to the difficulty in directly researching the human body, such as how the parameters of the neuro-musculo-skeletal system change after undergoing muscle strengthening, this study took advantage of using a neuro-musculo-skeletal model and a forward dynamics simulation. A forward dynamics computer simulation that was developed and validated in previous studies [9–11] was also used in this study. An independent neural input (represented as the set of activation patterns of all the muscles) was used as the simulation's input and the jump dynamics were calculated as an output.

The musculo-skeletal model used in this study is presented in Figure 1. It was three-dimensional and consisted of nine rigid body segments (head-arms-trunk, right and left upper legs, right and left lower legs, right and left feet, and right and left toes) with 20 degrees-of-freedom. It was free to make and break contact with the ground, where the foot-ground interaction was modelled as a set of exponential spring-dampers which were placed under each foot [12].

For the starting position, the body was assumed to be in a static squat position with the heels flat on the ground. Passive elastic joint moments were applied to each joint. The passive elastic moments of the hip extension/flexion, knee extension/flexion and ankle dorsi/plantar flexion were applied to the model as a set of equations as described by Riener and Edrich [13]. The remaining passive moments were applied as exponential equations as reported by Anderson and Pandy [12].

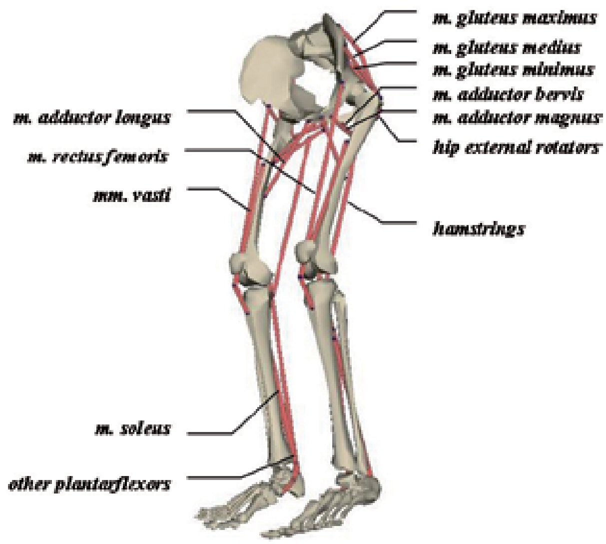

Figure 1. The neuro-musculo-skeletal model used in this study. Muscle paths were defined for the 26 major muscle groups used in a squat jump. Since the model is bilaterally symmetric, the same muscle paths are used on the left and right sides of the body

The model included 26 major muscle groups of the lower extremities. These were modelled as a Hill-type muscle, which consisted of a contractile element and a series elastic element [6]. Muscle paths and tendon slack length were derived from the work of Delp [14]. Muscle parameter values, such as the optimal contractile element length, maximal isometric force of the contractile element and pennation angle, were derived from data that were reported in other literature [15–17]. The values of these parameters are presented in Table 1.

Table 1. The parameters of muscle tendons used in the model. The abbreviations are: GMAXI (m. gluteus maximus), GMEDI (m. gluteus medius), GMINI (m. gluteus minimus), ADDLO (adductor longus), ADDMA (m. adductor magnus), ADDBR (m. adductor bervis), HEXRO (hip external rotators), HAMST (hamstrings), RECTF (m. rectus femoris), VASTI (mm. vasti), GASTR (m. gastrocnemius), SOLEU (m. soleus), and OPFLE (other plantar flexors)

Muscle	Peak Isometric Force (N)	Strengthened Peak Isometric Force (N)	Pennation Angle (deg)	Optimal Fibre Length (m)	Tendon Slack Length (m)	PCSA (cm^2)
GMAXI	1,883.4	2,260.1	5.0	0.1420	0.1250	59.79
GMEDI	1,966.2	2,359.4	8.0	0.0535	0.0780	62.42
GMINI	848.6	1,018.3	1.0	0.0380	0.0510	26.94
ADDLO	716.0	859.2	6.0	0.1380	0.1100	22.73
ADDMA	1,915.8	2,299.0	5.0	0.0870	0.0600	60.82
ADDBR	531.1	637.3	0.0	0.1330	0.0200	16.86
HEXRO	1,512.0	1,814.4	0.0	0.0540	0.0240	48.00
RECTF	1,353.2	1,623.8	5.0	0.0840	0.4320	42.96
HAMST	3,053.6	3,664.3	15.0	0.0800	0.3590	96.94
VASTI	6,718.3	8,062.0	3.0	0.0870	0.3150	213.28
GASTR	2,044.4	2,453.3	17.0	0.0450	0.4080	64.90
SOLEU	5,880.7	7,056.8	25.0	0.0300	0.2680	186.69
OPFLE	3,137.1	3,764.5	12.0	0.0310	0.3100	99.59

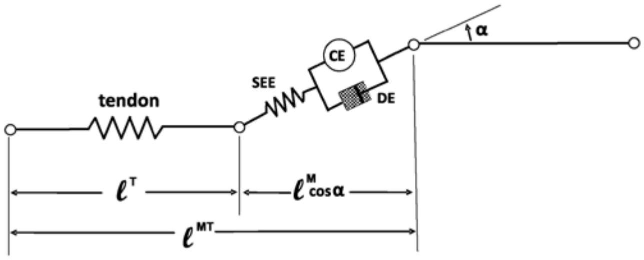

Figure 2. The schematic representation of a Hill-type muscle model. In the model, the series elastic element (*SEE*) represents the passive elasticity of tendons and all muscle fibres in the musculo-tendon complex, while the contractile element (*CE*) represents the active force developed by all muscle fibres, and where the damping element (*DE*) represents the viscosity of muscle fibres. The pennation angle between the muscle fibres and the tendon is parameterized with an additional constant (ℓ). The length of the musculo-tendon complex (ℓ^{MT}) is then computed as a sum of the tendon length (ℓ^{T}) and muscle length (ℓ^{M}) times the cosines of the pennation angle

Neural control was based on the activation patterns of the 13 muscles. Because the squat jump has been assumed to be bilaterally symmetric, identical neural control signals were sent to the muscles of both legs. Each muscle activation pattern was specified by three variables: onset time, offset time and the magnitude of muscle activation. A first-order differential equation described the delay between a muscle's activation and its active state [18].

The optimal muscle activation pattern was found through Bremermann's optimization method [19], wherein the maximum height reached by the body's centre of mass was used as the objective function. In the optimization process, onset time and offset time of muscle activation ranged between zero (simulation start time) and 0.5 s (simulation end time) and the magnitude of muscle stimulation had a range of zero (no excitation) to one (muscle fully excited). Hence, virtually any value in those ranges could be chosen as a result of the optimization process.

In order to study the effect of increasing muscle strength, the maximum isometric force of the muscles had to be increased. 85 separate simulation trials were used in this study where 26 muscles were included in the model which was used in each trial. Interestingly, only 16 out of the 26 muscles were active during the jump, as the remaining 10 muscles were found to be inactive in the squat jump: the m. gluteus maximus, m. adductor magnus, hamstrings, m. rectus femoris, mm. vasti, m. gastrocnemius, m. soleus and other plantar flexors.

In separate trials, the maximum isometric force of the muscles was increased by 5%, 10%, 15% and then up to 20%. During the simulation trials, the muscles were strengthened all at once, in groups or each one individually in each trail. In addition, when muscles are strengthened, the properties of the biomechanical system change, therefore the previous muscle activation pattern is no longer optimal and must be readjusted. Therefore, after each simulation trial, a numerical optimization of the muscle activation pattern was applied to find a new jump motion.

Results

In all the simulation trials, the numerical optimization procedure generated a natural-looking and smooth squat jumping motion. Figure 3 presents a jump motion of the model with original muscle strength (before the strengthening trials), in which the jump height was 34.57 cm. In order to validate the simulation used here, the generated optimal jump pattern was compared with published data from other literature (such as in [12], [6]) and was found that the model can reproduce all the salient features of a human jump.

It was also observed in all the strengthening trials that the muscles, which were strengthened, generated more force during the push-off phase. In addition, the amount of knee extension, ankle plantar flexion, hip flexion and joint moments all underwent change.

The effects of muscle strengthening on jump height are presented in Figure 4. Jump height increased the most after the strengthening of either the ankle monoarticular plantar flexors or the knee monoarticular extensors (with a height of 1.45 cm each when the muscle strength was increased by 20%). The sum of the jump height which increased when each of the muscles were individually strengthened was virtually the same when all the muscles were strengthened simultaneously (a difference of ≤ 2 mm). However this

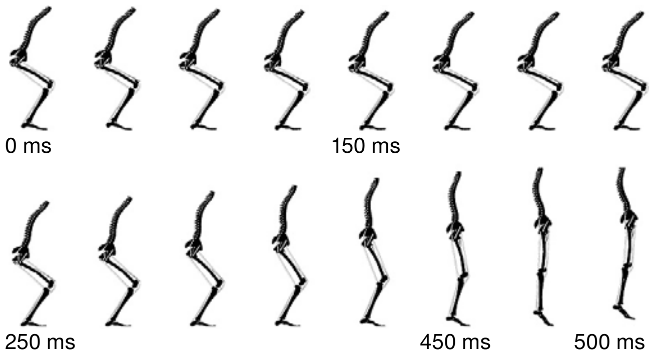

Figure 3. The diagram shows the optimal control of a squat jump as generated in this study. As can be seen here, the physical motion was both natural looking and smooth. All of the diagrams are equally spaced in time (Δt = 25 ms). The push-off phase started ~150 ms into the start of the simulation. The delay in time from when the jump began was due to the muscles needing to develop initial forces. Therefore, the initial movement presented in the first figures caused only minimal changes in captured body movement that was observed

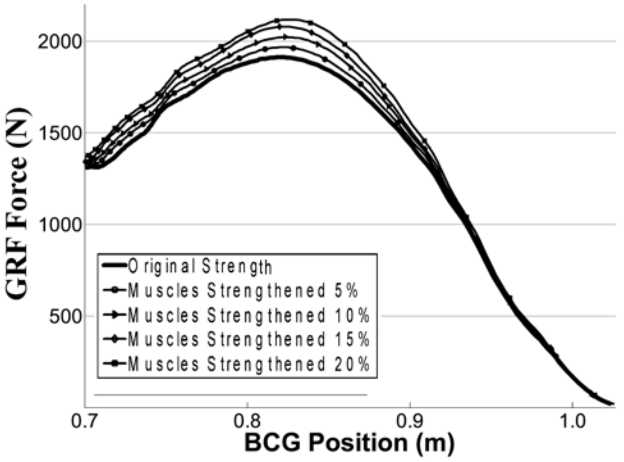

Figure 4. Presented here is the vertical component of the Ground Reaction Force plotted as a function of the height of the body's centre of gravity (BCG). All the muscles were strengthened equally. It can be seen that the Ground Reaction Force (GRF) increased almost proportionally to the increase in muscle strength. The Ground Reaction Force increased evenly due to the fact that when all of the muscles were strengthened equally, the torque at all the joints increased evenly, which resulted in the increase being almost proportional to the increase in muscle strength, as mentioned in the main body of this paper

was not true when a whole group of muscles were strengthened, here, the sum increase in jump height resulting from the strengthening of individual muscles did differ from the increase in jump height resulting from when a group of muscles were strengthened simultaneously. In the case of some muscles, jump height increased far more when the muscles were strengthened as a group. This was the case when strengthening the m. soleus and m. rectus femoris as well as the mm. vasti and hamstrings when they were strengthened as a group. On the other hand, the strengthening of some muscles (e.g. m. adductor magnus and hamstrings) as a group increased jump height less than the sum increase in jump height when these muscles were strengthened individually.

Jump height increased the greatest amount after the strengthening of the monoarticular hip extensors jointly with the monoarticular knee extensors (an increase of 2.93 cm when strengthened by 20%) or ankle plantar flexors (an increase of 2.6 cm). An increase in the strength of the monoarticular knee extensors jointly with the hamstrings was also very effective in increasing jump performance (by 2.44 cm).

In some trials, muscle strengthening was found to be ineffective since the strengthened muscle groups did not lead to a higher jump. In these cases, the additional force produced by the muscles did not contribute significantly to an increase in jump height because there was no mechanical solution in which the higher force produced by the strengthened muscles could be effectively used to increase the vertical acceleration of the body's centre of gravity (Fig. 4). This was observed when the hip extensors together with the hamstrings were strengthened as group, or when the m. rectus femoris and the m. gastrocnemius were strengthened as a group. In these cases, the increase in jump height was small.

In all the simulation trials, the jump height was found to gradually increase as the muscles were increasingly strengthened. In the case where all the muscles were simultaneously strengthened, the increase in jump height was nearly proportional to the increase in muscle strength.

When all the muscles were strengthened progressively, the parameters that characterise kinetic forces also gradually increased. A steady increase was recorded for ground reaction forces (Fig. 4), segmental power, joint torque and the total force generated by the muscle. The increases of these results were almost proportional to the increase in muscle strength. On the other hand, the changes in neural control and the force of each of the muscles were not always regular and proportional to the increase of muscle strength. For instance, when all the muscles were strengthened, the neural adaptation in the m. gastrocnemius and m. soleus was done in two different ways. In the first adaptation pattern, the m. gastrocnemius generated more force as the muscles were strengthened, while the force of the m. soleus went unchanged, but was only delayed in time (Fig. 5). In the other pattern, the force generated by the m. soleus increased while the force of m. gastrocnemius was delayed in time and increased only slightly.

In 32 trials, only one muscle was strengthened and the force generated by the individual muscle increased almost proportionally to the increase in strength, while the forces of other muscles altered in reaction to the muscle that was strengthened. For instance when the mm. vasti was strengthened, the forces of m. soleus and other plantar flexors notably decreased. When the hamstrings were strengthened, the m. rectus femoris created forces earlier. When the m. soleus was strengthened, it had the effect of increasing the forces of the m. adductor magnus. When all the muscles were strengthened, the total force generated by the m. soleus did not increase, instead, muscle power increased.

In the case when all muscles were strengthened together, the increase in jump height was greater than when only one muscle was strengthened, but the kinematics changed less than in the case when only one muscle was strengthened. The strengthening of the monoarticular knee extensor (mm. vasti) and hamstrings resulted in the greatest difference in jump kinematics (Fig. 6).

The scale of change in muscle forces and kinematics were related. The more the forces changed, the more jump kinematics differed from the jump of the musculoskeletal system with original muscle strength. The

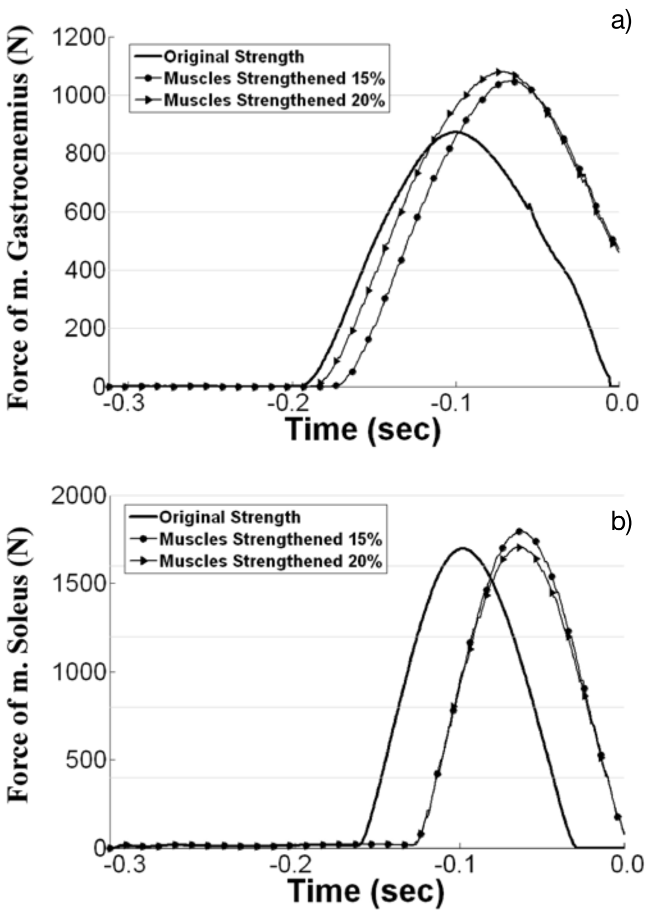

Figure 5. The figure shows the adjustment pattern in the force of the m. gastrocnemius (Fig. 5a) and the force of the m. soleus (Fig. 5b) in three different simulation trials. The first bold line depicts the muscle force in a jump with original muscle strength. The other two lines represent the adjustment patterns in muscle force in trials where all muscles were strengthened by 15% and 20%, respectively. It can be seen that the adjustment in muscle force was done in two different manners, as mentioned in the main body of this paper

biggest changes in muscle forces and kinematics were recorded after the strengthening of the mm. vasti, hamstrings, m. adductor magnus, and other plantarflexors. The scale of the changes of muscle forces depended on which muscles were strengthened and on how much they were strengthened, while it did not depend on the scale of neural adjustment.

In most of the trials, an adjustment of muscle control was essential in increasing jump height after muscle strengthening. The most important was the adjustment of control of the hamstrings and mm. vasti. When such control was not adjusted, jump height in fact declined by 3.85 cm and 1.60 cm respectively when strength was increased by 20%. When these muscles were strengthened together, jump coordination did not deteriorate as much, but the overall effect on increasing jump height without control adjustment was only +2 mm for 20% stronger muscles, which is a very insignificant amount.

In some trials, there was no need to adjust neural control. For instance, when the m. rectus femoris, m. gastrocnemius and the m. soleus were strengthened by 20%, the difference in jump height between a jump in which neural control was adjusted and a jump without any neural adjustment was less than one millimetre. After each of the above mentioned muscles were strengthened, maximal height jump was generated without adjustment in neural control. In these cases, the adjustment in neural control was very slight, while the forces of some muscles changed significantly (Fig. 7).

It was found that after the strengthening trials, in order to maintain jump performance, it was important to adjust the neural control of only some muscles, whereas neural adjustment of others had an insignificant effect (the difference in jump height after adjustment of these muscles was about 1 mm). Neural control of some muscles was not adjusted at all. For instance, in the case when the mm. vasti was strengthened, it was important to adjust neural control of the m. adductor magnus, hamstrings, mm. vasti and other plantarflexors, whereas neural adjustment of the m. gluteus maximus, m. rectus femoris, m. gastrocnemius and m. soleus had a negligible effect on jump performance.

When all muscles were strengthened, the neural activation of the biarticular hamstrings was delayed rela-

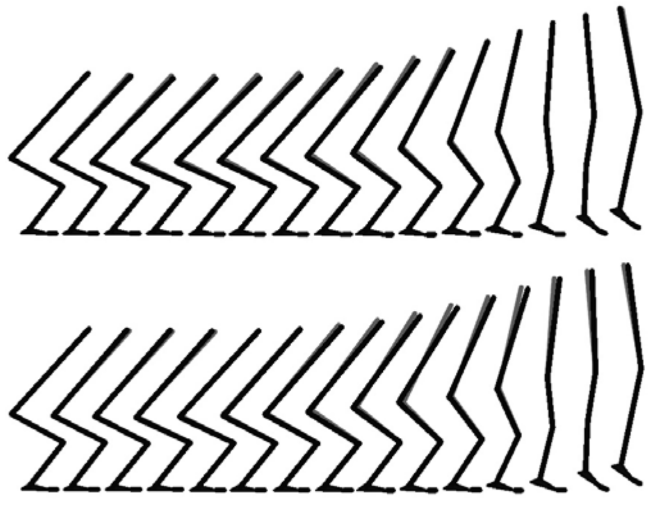

Figure 6. Stick diagrams show the effects of strengthening all the muscles together by 20% (upper diagram) and strengthening only the mm. vasti muscle (lower diagram) by 20%. The optimal jump motion (dark black lines) is compared to the jump after strengthening (lighter grey lines). All diagrams are equally spaced in time (Δt = 0.03 s). The abbreviations used here are PO, for the beginning of push-off, and TO, for take-off. It can be seen that jump kinematics and segmental coordination changed more after strengthening only the knee monoarticular extensors than in the case when all of the muscles were strengthened together

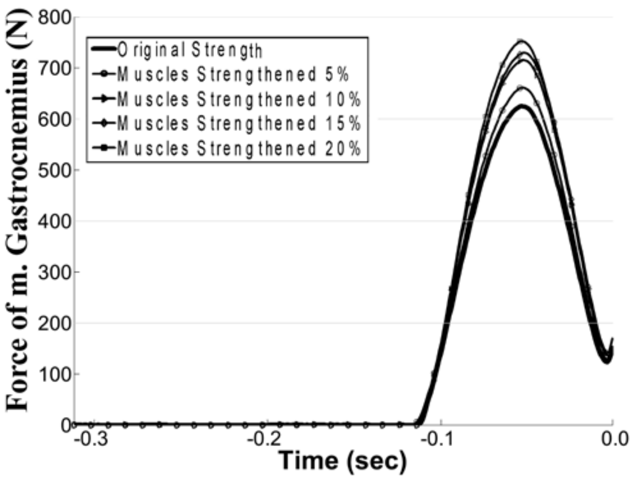

Figure 7. The figure shows the force of the m. gastrocnemius in the trials, in which only the m. rectus femoris was strengthened by 5%, 10%, 15% and 20%, while the m. gastrocnemius was not strengthened. When the m. rectus femoris was strengthened, the forces of the other muscles adjusted idiosyncratically in such a way that jump coordination was optimal without needing neural control to be adjusted. The largest adjustment was recorded in the forces of the biarticular muscles

tively to the monoarticular knee extensor (mm. vasti) while the monoarticular plantarflexors were activated earlier. Minimal adjustment of the onset time of muscle activation was observed for the m. soleus (~1 ms when strengthened by +5%) while maximal adjustment was observed for the hamstrings (~4 ms when strengthened by +5% and ~16 ms when by +20%). The time interval wherein the muscles were active (from turn-on to turn-off) increased for muscles spanning the hip and knee joint and tended to decrease for the ankle plantar flexors (especially m. soleus). The adjustment of neural control of the biarticular muscles m. rectus femoris and m. gastrocnemius was irregular.

Discussion

The aim of this study was to investigate the effects of muscle strengthening on neuro-musculo-skeletal dynamics. The results of strengthening muscles as obtained in this study are very similar to the experimental results reported in other literature. The increase in jump height (after strengthening the muscles by 20%) in our study was 17.5%, which was comparable to the 10–21% increase in jump height as reported in other literature [4, 5]. In the case when all muscles were strengthened by 20%, the knee torque in our simulation increased by 27.2%, and this value is also very similar to the experimental results found in other literature where knee torque increases of 20–30% were reported [3].

This simulation was composed of many different trials. In some trials, only some muscles were strengthened while in other trials all the muscles were strengthened equally. It seems that when all the muscles are strengthened equally, the main effect is an increase of joint torque, which is almost proportional to the increase of the muscles strength. The increase in muscle forces and segmental power is also nearly proportional to the increase of muscle strength, while the duration of push off shortens only slightly.

In the case when all muscles are equally strengthened, the neural control for every muscle changes, where the amount of adaptation of each of the muscles is relatively small, with the adjustment of neural control also being relatively small for all muscles. Similarly, since neural control affects inter-muscular coordination, changes in inter-muscular coordination are also small. Consequently, the adjustment of motion is also small. On the other hand, when only some muscles are strengthened, inter-muscular coordination changes more significantly, because the amount of neural adjustment is much larger for each muscle when compared to all of the muscles being strengthened equally. Therefore, the adjustment in motion is also large.

The more inter-muscular coordination changes, the more the kinematics involved during a jump change. The pattern of kinematical changes is greater when only some muscles are strengthened compared to when all muscles are equally strengthened. Interestingly, in the case when only some muscles are strengthened, not only does the neural control of the strengthened muscles adapt to the changes, but also the neural control of non-strengthened muscles. This is due to the fact that when some muscles are strengthened, the neural control of those muscles not strengthened must adapt in order to change inter-muscular coordination and motion effectively. If not, then maximum height cannot be reached during a jump. Therefore, the neural control of the remaining muscles that are not strengthened must also adapt in order for inter-muscular coordination to change in a way allowing the extra force of the strengthened muscles to be used effectively in maximizing jump height.

Consequently, the change in inter-muscular coordination depended upon how many and which muscles were strengthened, which in turn had an effect on the jump motion. Therefore, when only some muscles are strengthened, changes in muscle exertion patterns and in the body segmental dynamics are much larger compared to when all muscles are strengthened equally.

In summary, the relationship between an increase in muscle strength and the changes in neural control is complex. Firstly, in the case of strengthening all of the muscles, neural control is adjusted only slightly. Secondly, the adjustment of neural control of only some of the muscles is important for coordination. Thirdly, the magnitude of the changes of neural control (of those important muscles) depends on how much the muscles were strengthened.

The adjustment pattern of the muscle forces is not only irregular but also compound. It was observed that after strengthening, some muscles developed more force, while others developed a similar amount of force in a shorter time interval, and in the case when all muscles were strengthened, some muscles developed even less force than before strengthening, but their action shifted in time.

One important finding evident in our results is that the strengthening of some muscles did not require an adjustment of neural control. It was postulated previously [6] that after muscle strengthening, muscle coordination deteriorates and, therefore, an adjustment of neural control is indispensable in order to restore optimal control and generate a maximum jump height. Conversely, the results of strengthening the m. soleus, m. rectus femoris, and m. gastrocnemius suggest that in some cases, the adjustment of neural control is not required and that muscle forces adjust idiosyncratically in such a way that jump coordination becomes optimal.

When analysing more closely the adjustments of muscles, exertion patterns and neural control, it becomes clear that there is more than one adjustment pattern that leads to virtually the same kinematics and maximal jump height. The results of muscle strengthening demonstrated, for instance, that adaptation of neural control and exertion patterns of the m. soleus and m. gastrocnemius are linked and lead to virtually the same kinematics.

It also seems that the adjustment of neural control is done in an adaptive manner. The results of additional experiments confirmed this observation. In the experiment, the optimal neural control patterns were reached were recorded when the musculoskeletal systems were strengthened, in separate trials, by 5%, 10%, 15% 20%. Then, the optimal neural control from these jumps was re-applied to the musculoskeletal system with muscles strengthened by 20%. On the basis of this information, it was observed that jump coordination and jump height gradually improved.

Therefore, it can be postulated that even though the adjustment of neural control and muscles exertion patterns is complex and non-linear, the process of adjusting neural control and the muscle exertion pattern is done in an adaptive and progressive manner.

In this study a biomechanical model and simulation approach was used to investigate the motions of the link-model, the differential equations of muscle activation, and the patterns of muscle exertion. Regrettably, it is impossible to confirm these findings by direct experiments in vivo. On the other hand, the usefulness and reliability of such a forward dynamics approach has been examined and was confirmed in a number of studies.

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BIOMECHANICAL STUDIES ON RUNNING THE 400 M HURDLES

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ABSTRACT
Purpose. Biomechanical research conducted on hurdling are the basis for analysis of technique used in running disciplines. However, the 400 m hurdle run is an athletic discipline rarely subjected to individual biomechanical study. The aim of this study was to introduce the various forms of biomechanical studies on this difficult-to-quantify athletic event. **Methods.** In this study, 64 biomechanical articles were assessed, each covering various topics such as kinematics, dynamics, accelometrics and rhythm knowledge in the both the men's and women's 400 m hurdles. This was conducted with regard to the specificity of studies on the 400 m hurdles, including their types, methods and difficulties. The characteristics of the study were divided, among others, into: physiological effort, centrifugal force, dynamics of movement, stride rhythm, the level of abilities, laterality and type of body build. **Results.** Numerous sources allowed the creation of a general outline of present biomechanical studies. **Conclusions.** Within the context of the conducted analysis on the present state of biomechanical analysis on the 400 m hurdles, a number of basic principles were outlined that could determine the effectiveness of future research possibilities for scientists on the 400 m hurdles.

Key words: 400 m hurdles, biomechanics, kinematic, rhythm

Introduction

Track and field athletics is a discipline of sport that includes nearly 30 different forms of competition that test various fitness (motor) abilities and specific sporting techniques. The group of competitive sports that predominantly require fitness (motor) abilities include all forms of sprint and endurance competition (from the 800 m race to the marathon). The types of track and field events that have a significant (and sometimes dominant) component of testing motor skills and coordination (in sport, both of these components are classified as *technique*) are largely those that involve jumping and throwing.

Hurdling is a form of track and field competition that mixes both motor abilities (with emphasis on speed, dynamic strength and anaerobic endurance) and specific motor skills [1–3]. The first attempts at assessing the technical skills of sprint hurdle races occurred already at the beginning of the 20th century, when Frederick Webster compared the techniques of two hurdlers, the American Alfred Copland and English A.C.M. Croom [4]

The beginnings of such research on running technique were mainly based on observation and images, which included artistic paintings, stroboscopic observation, and the application of photography, especially time-lapse photography, being the early prototype of timed-sequence sports photography [5].

However, analysis of the techniques used in the hurdle run, on the basis of the above mentioned methods, only took on a larger role much later [6]. Those early attempts of analysis focused primarily on the more basic forms of physical activity in track and field, such as running, jumping and throwing [7]. A return to the imaging methods which evaluate the movement present in hurdling took place only after World War II and continues to this day [8].

The initial forms of assessing the techniques present in hurdle races were focused on sprint distances, such as the men's 110 m hurdles or the women's 80 (100) m hurdles [9–14]. However, the 400 m hurdles was, and still is, overlooked in the biomechanical analysis of track and field sports. Although both hurdle distance are frequently treated as one group of competition, there are fundamental differences between them, as found in biomechanical studies, where the most important of which are provided in Table 1.

The 400 m hurdles is one of the most interesting yet difficult track and field competitions. The characteristics of this form of competition can be made by using such phrases as "relative" or "indirectly related to". Here are some examples:

1. The 400 m hurdles is still a "relatively" new form of competition, the first records in the 110 m hurdle were first noted only in the mid-19th century; for the 400 m hurdles, only 50 years

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Table 1. The specificity of the 100/110 m sprint hurdle and the 400 m long hurdle

Criterion	100/110 m hurdle	400 m hurdle
1. Direction of travel	Straight course run	Straight course run with turns
2. Energy metabolism	Aerobic – non-lactate	Anaerobic – lactate
3. Hurdle technique	One leg (only the right or left leg attack)	Both legs (both right and left leg attack)

later. Women began competing in the 400 m hurdles only in the 1970s.
2. Training for the 400 m hurdles begins "relatively" late, training first begins at the 200–400 m distances and sprint hurdles, only later is professional training for the 400 m hurdles provided
3. The 400 m hurdles is a "relatively" high-speed distance, "relative" to characteristics of endurance
4. Taking into consideration the motor and technical aspect, it can be stated that the 400 m hurdles is a form of competition that "relatively" tests fitness, which is "relatively" dependent on the technical ability to attack the hurdles

It may be that perhaps that due to the complexity of this competition, scientists which conduct biomechanical research on this sport avoid studies that involve the 400 m hurdles. In many instances, in view of the small number of publications related solely to the 400 m hurdles, this discipline was subject only to comparative analysis with sprint distances.

Therefore, the aim of this work is to present the state of biomechanical studies of the 400 m hurdles. It will take into account the historical aspect of these studies as well as the current problems associated with the objects, methods and types of analyses.

Material and methods

This study could be considered topical. In the analysis conducted herein, literature related to the wide array of biomechanical problems present in hurdling was used. In addition, a survey that was conducted by this team on a group of hurdlers during 1996–2008 was considered [2, 6, 15–22].

Analysis of the literature related (directly or indirectly) to the 400 m hurdles found that there are three basic types of approaches used (Tab. 2).

In race research, the main kind of analysis involves studying accelerometrics and study of so-called rhythmic stepping, which is performed between successive hurdles. Race analysis of the 400 m hurdles focus largely on the world's most important competitions, such as in the 2000 Olympic Games in Sydney [23]. In some cases this kind of analysis is conducted on athletes competing at a lower level [24]. However, conducting research on the kinematic structure of race conditions is quite difficult and not very popular [25].

The most significant, from a scientific perspective, is research conducted in field conditions, as a control element of training organized at a stadium. An analysis of the literature finds that, in 400 m hurdles, there is lack of standardized test procedures, and that those studies focused only on training and research solutions aimed at substituting classic forms of competition for testing purposes. In this group of studies, research can be found on 400 m hurdles test training [26], ideas on the concept of consecutive running [27] and on the concept of running at intervals [21, 28]. The details are presented in Table 3.

The smallest group of studies conducted on the 400 m hurdles are those of laboratory analysis. They focus mainly on issues related to strength as a static condition [29].

The difficulties in organizing studies on the movement structure and dynamics in the 400 m hurdles are due to a variety of reasons (Tab. 4). The regulations of the race (on different tracks, the positions of the hurdles in different spots), the specificity of training for competition (races are only in the summer) and a number of methodological dilemmas significantly impede conducting such tests.

The organization of biomechanical research on the 400 m hurdles requires a broader look at the specificity of both motor and technical skills in competition. It is difficult to directly transpose the results of studies conducted on the 110 m hurdles to the 400 m hurdles. The determinants of such biomechanical studies are presented in Table 5.

Attempts at conducting biomechanical analysis of running in the 400 m hurdles were concerned about previous research and studies connected with the improvement of the methodology and practical application of the results of empirical analysis to sports training. This problem can be presented as several points, some of which are emphasized below.

1. Methodological problems connected with biomechanical studies on the 400 m hurdles

An assessment of running techniques used in hurdles is based on biomechanical studies that are mostly focused on sprint distances, the men's and women's 100/110 m hurdles [6]. Started in the 1950s, attempts at objectively assessing the techniques of sprint hurdle races in the 1990s led to a discussion on the validity and reliability of the selection of the parameters that were used to assess the appropriate style of running [30–33]. Studies conducted on the 400 m hurdles pri-

Table 2. The types of biomechanical studies conducted on the 400 m hurdles

No.	Type of study	Characteristics	Sources
1.	Races	Analysis conducted during competition, most commonly the Olympics and in world, European, national or regional championships	8, 9, 10, 11, 17, 23, 24, 35, 46, 49
2.	Training (field)	Analysis conducted during training, frequently simulating competition	13, 14, 15, 16, 19, 28, 30, 31, 32, 36, 37
3.	Laboratory	Analysis supplemented with physiological and biochemical methods, analysis based on motor theory (e.g., from feeling the so-called sensation of rhythm) performed on a treadmill or (worse) on a ergometer	29, 38, 42, 43, 44, 54, 60, 61, 64, 67

Table 3. The organization of biomechanical research on the 400 m hurdles

Author, year, source	Type of analysis	Research procedure	Subjects
Röll, 1976 [26]	Cinematic and dynamographic analysis	Hurdles in the 3rd, 5th, 9th position in the third lane (400 m hurdles run based on standard regulations)	women (n = 8), low-level athletes
Schwirtz, 1990 [28]	Cinematic and dynamographic analysis	Racing with a 7-step rhythm (19 m distance) in two different variations: 1) at rest (3 hurdles) + fatigue (interval of 2 × 3 hurdles) 2) attacking the hurdles with both right and left leg	men (n = 6), high-level athletes
Iskra et al., 2000 [21]	Cinematic analysis, analysis of training loads	200 m run (in 24 s), 1 min break as well as a run over 5 hurdles (91 cm, distance 17.50 m) – the 4th hurdle was filmed	European champion in the 400 m hurdles
Dakin, 2008 [27]	Analysis of running speed (“hurdles effectiveness”)	Running over hurdles placed on a straight (2–4); speed cameras positioned 5 and 10 m before hurdle nr. 3, the analysis included 2–3 runs of each attacking leg	a project for the athletes of a national team

Table 4. The difficulties involved in conducting biomechanical studies in the 400 m hurdles

No.	Difficulty	Specific questions
1.	Methodological	– number of times to repeat the run (a short distance is not a problem, but 9–10 hurdle runs?) – what is important, the splits, number of steps, or other kinematic parameters? – are tests performed during training reflected in true competition?
2.	Logistical	– how to conduct studies in winter conditions? – how to invite the best players during a variety of preparations?
3.	Regulations	– how to organize the study, each run performed on a different track? – how to organize analysis in field studies under conditions different from race regulations?

Table 5. Factors that determine the organization of biomechanical research on the 400 m hurdles

No.	Aspect	Characteristics
1.	Physiological work	running at the beginning (non-lactate) and second (lactate) half of the distance
2.	Centrifugal force	running on a straight course and with turns (on lanes 1 to 8)
3.	Running dynamics	running the 400 m hurdles involves 10 take-offs and landings
4.	Running rhythm	running the 400 m hurdles requires maintaining the proper proportion of steps, between those steps taken and the “rhythmic units” (the distance between hurdles)
5.	Lateralization	attacking the hurdles with both right and left legs
6.	Preparing physical fitness	the ability in effectively attacking the next hurdles depends on the level of motor abilities, mainly speed, strength and endurance
7.	Body build	the rhythm of the steps depends on an athlete’s somatic build, mainly his body height and leg length
8.	Coordinative abilities	connected with rhythmic ability and the ability to maintain the so-called hurdle rhythm

marily used accelometric analysis (see below); only in a few cases were efforts made at determining the methodological basis of biomechanical studies [21, 28]. These attempts, however, failed to arrive at clearly formulated conclusions as to the selection of the best options for testing in accurate, reliable and standardized conditions.

2. The selection of kinematic parameters in the evaluation of running techniques used in the 400 m hurdles

The most frequently used parameters in the evaluation of running techniques in hurdles were from movement kinematics. Such studies appeared during the 1980s and 1990s [9, 10, 34–36] and were highly diversified (both methodologically and thematically). The search for relevant factors that could assess the structure of hurdles running were concerned with several to several dozen parameters. However, in a few studies conducted on the 400 m hurdles, some of the selected parameters do not seem to be representative in assessing the effectiveness of various running techniques. In studies conducted by Iskra and Bacik [37], four basic parameters (mainly different stride lengths) were included; in Bollschweiler [35], 14 length and angular parameters were selected. The current state of research on the kinematic parameters of hurdles running (especially in attacking hurdles) for the 400 m distance does not allow for the strong selection of accurate and reliable timing, spatial and time-space parameters.

3. Dynamometric tests and the specificity of the 400 m hurdles

Research on ground reaction forces by using tensometric and piezoelectric platforms provides an indispensable element in biomechanical studies in track and field athletics, including hurdling. The increasingly widespread use of the devices produced by the Swiss company Kistler allows one to obtain relevant information on running the 400 m hurdles. As a general characteristic of the competition, the 400 m hurdle race is composed of a sprint with the need of jumping over 10 obstacles. Each take-off and landing is an indispensable part of the 400 m hurdles [18]. In empirical studies conducted on hurdling, dynamometric analysis was conducted by Rölla [26] and was also considered by the Polish hurdlers Dworak et al. [38].

4. The energy specificity in the 400 m hurdles and changes in hurdling technique

Scientific analysis on the 400 m distance (also with hurdles) found that maximum effort performed in a time less than 1 min was dominated by transformations of an aerobic-lactate character with some non-lactate (typical in sprint distances) and aerobic changes, typical in endurance races [39-41]. Attempts at organizing training course in the 400 m hurdles in accordance with the demands of energy exertion were presented earlier by Iskra [18]. Charatimowa [42] as well as Gupta et al. [43] noted that the effort in the 400 m distance, in terms of energy, is slightly larger than in the in the 400 m hurdles. Changes in the biomechanical parameters during a sprint (at intervals of 100–200–400 m) were presented by Nummela et al. [44].

The different stages of the 400 m hurdles race are presented in Table 6. These data indicate that the evaluation of running techniques in the 400 m hurdles should include two fragments and a beginning phase (hurdles 1–5) as well as fatigue phase (in the second part of the run). Preliminary analysis of the above problem were conducted by Ikwin et al. [45], in the 110 m hurdles, and by Schwirtz [28], in the 400 m hurdles. The results of the studies found that technique used in the first and final part of the race can vary considerably.

5. Accelometric research as the basis for biomechanical research in running the 400 m hurdles

Biomechanical analysis on running the 400 m hurdles has been from the beginning connected with the evaluation of hurdling techniques through the use of sequence photography and research performed on time differences in certain parts of the race. Accelometric analysis constitutes a major part of the publications published to date that merge the 400 m hurdles and the method of biomechanical research on human movement. Since the 1968 Olympic Games in Mexico, analysis in the changes of running speed in the 400 m hurdles have become an indispensable part of scientific investigation in this form of competition [24, 46]. These studies have become a sort of inspiration for studies conducted later in analyzing athletes of a lower level [24, 47].

Analysis in the changes of speed (and mainly its reduction after 150 m) are significant in the organization of sports training. Assessment of the differences between running "tactics" at different levels (juniors-seniors, women-men) is only the beginning for further research. Additional questions should be asked on the assessment of which parts of the run can be the most significant in winning the race. Not only are absolute results important (finishing times), but also the impact of deceleration during the race.

6. Running "rhythm" in the 400 m hurdles as the most used and most enigmatic term in competitive hurdling

The concept of rhythm, understood within the theory of motor coordination, is clearly formulated.

Rhythm in hurdling is a term that is found more in practical training and competition than in scientific literature. A review of the definition that is used to define "hurdling rhythm" in the 400 m hurdles was conducted by Iskra [47] and distinguished three variants:

1. Rhythm is the number of steps performed in each successive "rhythmic unit".
2. Rhythm as the number of steps in relation to the time spent covering the specific parts of the race (frequency of steps).
3. Rhythm is the optimized (in terms of the number of steps and running pace) form of running the entire distance in the shortest possible time by taking into consideration the level of preparation of one's motor skills, technique and somatic build.

This relatively expanded definition illustrates the complexity of "rhythm" in the 400 m hurdles. The number of steps taken in the nine successive distances between the hurdles implies using both the right and left legs to attack the hurdles, under different conditions of energy-related effort (rest-fatigue) and the course structure (straight or turn). Changes in the attacking legs of hurdlers with different rhythms are presented in Table 6 [22].

Table 6. Variants in step rhythm when running the 400 m hurdles within biomechanical studies in racing conditions

Hurdle	Rhytmic variant			
	A	B	C	D
1	L	L	L	L
2	L	L	P	L
3**	**L**	**L**	**L**	**L**
4	L	L	P	L
5	L	L	L	P*
6	L	P*	P	L
7	L	L	L	P
8	L	P	P	L*
9**	**L**	**L**	**L**	**L**
10	L	P	P	L

A – homogeneous rhythm (odd)
B – single alternating rhythm
C – homogeneous rhythm (even)
D – double alternating rhythm
L – attacking left leg, P – attacking right leg
* changes in the running rhythm
** jumping hurdles 3 and 9 has a similar movement structure (attacking left leg), regardless of rhythm choice
Figures in bold denote change in the running rhythm.

7. Attacking hurdles on the straight and turns – the problems of training and scientific analysis

Running the 400 m hurdles is an alternating combination of attacking hurdles on the straight and turns of the track. The running distance after the turn is considered one of the two most difficult parts of the race, the acceleration phase and the first phase of fatigue due to anaerobic work, closely tied with the changes of step rhythm (Tab. 6).

In the more than 100-year history of biomechanical research in sport, there is still no study which analyzes the problems of different techniques in hurdling on the straight and turns. The question of differences in the biomechanical parameters of running on the different parts of the course have only been conducted on a flat distance of 400 m [48]. If we were to add the level of fatigue (e.g., during the second turn) as a factor to the entire distance, the need for research on the techniques of attacking hurdles on turns appears to be even more necessary.

8. Lateralization (functional asymmetry) – not only scientific problems, but also of sport

The aspects of the human body's functional asymmetry are present in many sports that require the effective use of, mainly, two limbs (e.g., the left and right legs in soccer, the left and right hand in basketball or boxing). An excellent example of track and field athletic competition that takes the problem of lateralization into account is the 400 m hurdles. It is known that the "dominant" lower limb in hurdling is the left leg, which minimizes the negative effects of centrifugal force.

The specificity of the 400 m hurdles excludes (except in certain cases) the possibility of attacking the hurdles with only one lead leg. This is connected to instances of 13- and 15-step rhythm. However, such a concept is not entirely optimal within the context of a runner changing stride length. Due to increasing fatigue in the second part of the 400 hurdles race not only is there a reduction in speed, but also the hurdlers' stride length (from 3.73 cm to 3.39 cm). Therefore it appears that it is necessary for the hurdler to change his attacking leg, and by changing the attacking leg, we need to be aware of significant changes in the training process of hurdlers. Similar to how basketball and handball players, in certain circumstances, need to throw using either their right or left hand, the same applies for running in the 400 m hurdles, which involves using both legs for attacking hurdles.

Research conducted by Iskra and Walaszczyk [22] and Iskra [49] found that hurdlers in the 400 m hurdles exploit their strength in different ways (with their "dominant" leg) as well as using their weaker ("alternative") leg in different ways when attacking hurdles. However, the problems of the functional differentiation of the "attacking leg" have been more closely examined by trainers than by sport researchers.

9. The strength and direction of wind and changes in running rhythm in the 400 m hurdles

Accelometric research and cinematic analysis on the 400 m hurdles does not take into account the effect of wind speed and direction on the choice of the attacking leg, running rhythm and, consequently, on attacking hurdles. An example of the importance that weather conditions (in this case wind speed and direction) have on tactics and technique used in the 400 m hurdles was during the elimination trails during the Olympic Games in Sydney, when the wind force on the last straight was more than -4 m/s. Previous analyses on the impact of wind speed and direction on one lap race results were only conducted on the straights of a track [50–52].

Analyses in the changes of technique between the straights, by taking into consideration the impact of wind, seems to be necessary from the standpoint of practical training. This is particularly important in competition, which can take place in a variety of directions and on tracks of varying curvature. Some of the most radical changes are proposed by Mureika [53], who demanded the recalculation of competition results in sprint races by including wind strength and the height above sea level of where the competitions took place. Questions on the impact of weather on the way (style, technique) hurdling is performed still remain open. Recent analysis conducted by Quinn [53] provides interesting data on hurdling on different tracks during the same (measured) wind speed.

10. Comparison of the specificity of the 400 m hurdles to other track and field competitions

The history of running the 400 m hurdles has become a derivative of sprint hurdles race (110 m hurdles) and the 400 m dash. Comparisons (including biomechanical) among these three types of competitions have become popular in the evaluation of techniques in running the 400 m hurdles in the 1970s [55]. The understanding of the 400 m hurdles as an extended form of the 110 m hurdles have for long hindered biomechanical studies comparing it to completely different distances. Moreover, all studies on hurdling frequently combine both distances as one. Recent studies on the 400 m hurdles suggest that it is (mainly due to the obstacles present) connected more to the 3000 m [25, 26] steeplechase run. Thirty years of physical education progress was not enough to clearly state that the 400 m hurdles is a specific form of competition, distinct from the 110 m hurdles, 400 m dash or the 3000 m steeplechase. The main differences are provided in Table 7.

Table 7. Similarities and differences among the running events of track and field with the 400 m hurdles

Parameter	400 m hurdles	400 m dash	3000 m steeplechase
Length of effort	–	+	–
Obstable height	±	–	±
Distance between obstacles	–	–	–
Training	±	±	–

"–" – significant difference, "+" – substantial similarity, "±" – different interactions

11. The problem of motor control and the specificity of hurdles

The effort required in hurdling is connected to the repeatability of specific movement sequences in jumping over the hurdles and then running to the next obstacle. The so-called rhythmic unit [3, 57], in the case of running the 110 m hurdles, are associated with running in a 3-step rhythm, while running the 400 m hurdles requires a variable number of steps (12–19). Analysis of the movement sequences is characteristic of research in the field of motor control, where it is usually associated with movements with a limited aspect of mobility (e.g., typing, playing the piano, etc.) [58, 59].

Comparison of the movement sequences in the range of the so-called fine motors have in fact much in common with the rhythmic units present in the 400 m hurdles. Such a hypothesis was used in hurdles research conducted by Hay and Schoebel [60]. Clearing obstacles of low height during walking and running is a significant part of empirical research that borders with motor and biomechanical theory. Referring the experience of hurdlers in clearing obstacles finds that this group of track and field competitors can provide a stimulus for wider, non-sport empirical analysis [61, 62].

The problems associated with the use of biomechanical methods in controlling the training as well as assessment of competition in the 400 m hurdles is connected to numerous problems taken from the wider understood aspect of physical culture. Comprehensive analysis that takes into account a wide range of purely biomechanical problems as well as the necessary information on the theory of sports training, stress parameters, anthropometric measurements, etc., belong to the biomechanical studies of the past. This applies not only hurdling, but all professional sports.

Within the evaluation of the specific problems connected with the biomechanics of running the 400 m hurdles, several important aspects need to be taken into account:

1. The differences in the *method of teaching* hurdling techniques (e.g., analytic, synthetic, and recreational) that have an effect on improving hurdling techniques, assessed on the basis of selected kinematic and dynamic parameters [63].
2. The effect of *body build* (e.g., height or leg length) on selecting the optimal running rhythm or hurdling technique [64].
3. Changing *sports training* (which includes measures used in the improvement of motor skills

Table 8. A schematic for biomechanical studies on the 400 m hurdles (project)

Phase	Characteristics
1. Training	the volume of technical training, the proportion of training measures classified as "motor" and "rhythmical" (in hurdling)
2. Competition racing	assessing the changes in running rhythm, analysis of the time spent on each section of the course
3. Laboratory and field testing (dependent on the cooperation between the coach-researcher)	cinematic analysis of running in each of its phases: – running with the right and left attacking leg – running on the straights and turns – measurements during the beginning and final (fatigue) running phases – measurements before and after rhythm change
4. Analysis of running technique	assessing the key elements of techniques, whether positive or negative
5. Training modification	qualative and quantative changes
6. Repetition of competition race	evaluation of positive and negative changes

and technique) and the desired changes in hurdling technique [65].

4. Changes in the *regulations* of hurdling in terms of biomechanical analysis [66, 67]. There are many problems associated with biomechanical analysis performed on the 400 m hurdles. The past efforts of researchers could be considered being partial, and perhaps, even, rudimentary. Attempts at comprehensive research on hurdling have, so far, included only the 110/100 m hurdles [13, 56, 68]. There is a necessity in developing a comprehensive study on only the 400 m hurdles, with the proposal for such a study provided in Table 8.

Conclusion

Within the context of the conducted analysis on the present state of biomechanical analysis on the 400 m hurdles, a number of basic principles can be stated that could determine the effectiveness of future analyses.

– The recognition of the 400 m hurdles as a specific, autonomous form of track and field competition, which differs from sprint hurdles performed on the track straight
– The conducting of research on the kinematic physical movement structures present, based on both training and competitive conditions
– The search for methods to assess the movement techniques in training conditions (field testing)
– The search for parameters (time, kinematic and dynamic) that can be used with a high degree of accuracy and reliability
– The conducting of a comprehensive analysis that takes into account the expecations of researchers of different disciplines, as well as the knowledge of trainers

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ACUTE EFFECTS OF DROP JUMP POTENTIATION PROTOCOL ON SPRINT AND COUNTERMOVEMENT VERTICAL JUMP PERFORMANCE

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ABSTRACT

Purpose. Muscle post-activation potentiation (PAP) is a mechanism by which power twitch is increased after previous conditioning contractions. In this study, we determined the time-dependent effect of a loaded drop-jump protocol on sprint time and countermovement jump height in well-trained athletes. **Methods.** Ten athletes randomly performed the control and experimental protocols on two different days. As a pre-test, the athletes performed the vertical jump and 50 m sprint test for preload measurements. Then, the experimental or control protocol was randomly applied, where the control protocol was composed of the athletes remaining at rest for 10 min. In the experimental protocol, the athletes performed two sets of 5 drop jumps (0.75 m), with a 15 s interval between the jumps and a 3 min rest after each set. Then the vertical jump and 50 m sprint tests were performed again 5, 10, and 15 min after the protocol. **Results.** The experimental condition (drop jump potentiation protocol) increased performance in the vertical jump by 6% after 15 min ($p < 0.01$) and in the sprint by 2.4% and 2.7% after 10 and 15 min, respectively ($p < 0.05$). **Conclusions.** These findings suggest that the drop jump potentiation protocol increases countermovement vertical jump and sprint performance in high-performance athletes at different times, suggesting that PAP induction depends not only on the design of the protocol, but also on the effect of time and the type of exercise involved.

Key words: muscle post-activation potentiation, sprint, vertical jump, drop jump, performance

Introduction

The development of muscle power output is a determinant of sport performance, especially in track and field events that are composed of running short distances or vertical and horizontal jumps [1, 2]. Several training techniques for maximizing muscle power have been investigated in order to acutely improve sport performance, but the results found in literature are not conclusive [1].

Performance in sprint running is dependent on the ability to generate high velocity in a short time interval, which itself depends on numerous biomechanical, architectural and biochemical factors [3]. Various training approaches are commonly used to improve sprint performance, including sprint drills, overspeed training, strength training and plyometrics [4, 5]. Mero and Komi [6] suggested that the elastic properties of the muscles and their energy stores are necessary for high performance in sprint events. This fact supports the importance of power training to develop sprint potential. Plyometrics is a training method that develops the ability of muscles to produce force at high speeds (power output) in dynamic movements. This training is composed of muscle stretch followed by an explosive concentric contraction, known as the stretch-shorten cycle (SSC) [7]. Kotzamanidis [5] found that 10 weeks of plyometric training improved jump ability and running velocity in prepubescent boys. Similarly, Rimmer and Sleivert [8] reported a significant increase in sprint performance following sprint-specific plyometric training for eight weeks in male participants who had no experience with this kind of training.

In regards to acute power enhancement, several studies suggest that performance is increased after different protocols of muscle potentiation [9, 10]. This increase of acute power output has been related to post-activation potentiation (PAP) [11, 12]. PAP is a mechanism by which muscle contractile ability is increased by a previous bout of maximal or submaximal contractions [1, 13]. The precise mechanisms involved in PAP activation still remain unclear. Some theories

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have been suggested, such as an increase of phosphorylation in the light chains of myosin, which elevates the sensitivity of actin-myosin interaction to release Ca^{2+} from the sarcoplasmatic reticulum [13, 14], the modification of reflex activity in the spinal cord (H-reflex) [15], and the recruitment of a high number of motor units [1]. Previous studies have demonstrated that the manifestation of PAP depends on muscle characteristics, such as training status (particularly strength levels) [16], the distribution of fiber type [17], the contractile conditions (whether shortening or lengthening) [18], as well as an individual's training background (greater PAP in power athletes when compared to endurance athletes) [19].

Several potentiation protocols have investigated the effects of maximal and submaximal muscle activity on subsequent athletic performance [11, 20]. Traditionally, PAP has been induced by an application of a strength training stimuli (preload), such as a heavy-load squat [11, 21] and maximal voluntary isometric contraction [19]. Masamoto et al. [22] observed that one repetition maximum (1RM) performance was increased (by 3.5%) in trained athletes when executed 30 s after one set of two depth jumps. Young et al. [10] reported that a single set of 5 maximal repetitions of squats increased countermovement jump height (by 2.8%) when performed 4 min later in athletes experienced with squat exercise. Kilduff et al. [23] also found an improvement in countermovement jump performance (by 4.9%), determined after 8 min (post 8 min) of squat potentiation protocol (three sets of 3 repetitions at 87% 1RM). Weber et al. [24] found an enhanced peak height of squat jump (by 4.7%) when completed 3 min after one set of 5 repetitions of back squat jumps at 85% of 1 RM in track and field athletes. Smith et al. [10] reported an increase in power output in a 10 s sprint cycle test when performed 5 min after ten sets of 1 repetition of parallel back squats at 90% 1RM. McBride et al. [21] observed an improvement in 40 m sprint time (by 0.87%) in football players after 4 min of doing one set of 3 repetitions of heavy-loaded squats at 90% of 1RM. Chatzopoulos et al. [25] showed that 10 repetitions of heavy resistance stimulus at 90% of 1RM was able to improve running speed in the 10 and 30 m dash in amateur players of team games when executed 5 min later.

Although several potentiation protocols have demonstrated an improvement in sport performance, some studies did not find any effect. Scott and Docherty [20] observed that one set of 5 maximal repetitions of back squats has no effect on maximal jump height and distance measured 5 min later in resistance-trained men. McBride et al. [21] related that one set of 3 repetitions of loaded-countermovement jumps (CMJ) does not improve performance in the 40 m sprint when performed 4 min later. Hanson et al. [26] demonstrated that a single squat performed at 80% of 1RM does not improve vertical jumping performance when measured immediately after the potentiation protocol in resistance-trained athletes. Parry et al. [13] observed that 5 back squats at 90% of 1RM have no effect on maximal cycle ergometer performance when executed 20 min later in male rugby players. Moreover, Lloyd and Deutsch [27] did not observe any effect on sprint performance after a 3-repetition maximum squat (post-10 min) and showed an impairment in 5 m split and 20 m sprint times (post-10 min) by the countermovement jump potentiation protocol.

Thus, several methods to induce PAP have been suggested and studied in order to improve output power performance. However, it is difficult to compare the results as there are several factors involved in PAP induction, such as protocol design, maximal induction time, sport modality, fiber type distribution, contractile conditions as well as an individual's training background. Data available in literature on muscle PAP protocols and output power performance are not yet conclusive. Moreover, PAP induction at different times by the same experimental protocol in two different high power exercises has also not yet been investigated. Therefore, in this study we propose to evaluate the acute effects of one potentiation protocol (two sets of 5 repetitions of drop jumps) at different times (at preload and post 5, 10 and 15 min) on the performance of two high power exercises (the sprint time in the 50 m dash and countermovement jump [CMJ] height) in track and field athletes who have had at least 6 years of training experience in order to avoid any possible adaptation effects to the training protocol. This study was conducted as a randomized cross-over trial, where all participants performed the control and experimental protocols on two different days.

Material and methods

Ten male athletes were selected among the sprinters that represented the city of Guarulhos, Brazil in official track and field competitions. The participants were high-level professional athletes, regularly involved in jumping, sprint, stretching and power training activities and were experienced in both training and competition for at least six years. The age, body mass, and height of the group was: 20.6 ± 2.6 years; 73.7 ± 9.22 kg; and 176.4 ± 5.81 cm, respectively. Before involvement in the study, the athletes were informed about the objectives and methods of the study and signed a voluntary consent form. The athletes were instructed and accompanied at all times by a professional physical trainer in order to ensure that all of the procedures and techniques used in this study were performed correctly. This study was approved by the Research Ethics Committee from Cruzeiro do Sul University, São Paulo, Brazil (165/2008).

All of the participants randomly performed both the control and experimental protocols during two visits with 72 h rest between them in order to eliminate any possible crossover effects from the previous test. In addition, 24 h rest was given before the first day of testing. Just before each of the protocols, the athletes were submitted to a standardized warm-up (consisting of aerobic and stretching exercises).

Figure 1 illustrates the protocol conditions used in this study. Each protocol condition was performed on a different day. The control condition was composed of a standardized warm up, followed by 5 min rest. For pre-test measurements, the participants' countermovement jump (CMJ) and 50 m sprint results were determined. After the pre-test, the athletes had 5 min of rest and remained resting for an additional 5 min (as part of the control condition). Then they subsequently performed the CMJ and the 50 m sprint test again at intervals of 5 min, 10 min and 15 min after the control condition (rest).

The experimental condition was composed of a standardized warm up, followed by 5 min rest and then the CMJ and 50 m sprint test (for pre-test measurements). After the pre-test and 5 min rest, the athletes performed a drop jump (DJ) potentiation protocol composed of two sets of 5 drop jumps at a height of 0.75 m and were instructed to react as fast as they could to immediately execute a vertical jump. Two sets of 5 drop jumps were performed with 15 s rest between the jumps and 3 min rest between the sets. Finally, after the drop jump sets, the athletes subsequently performed the CMJ and 50 m sprint test 5, 10, and 15 min after the DJ potentiation protocol.

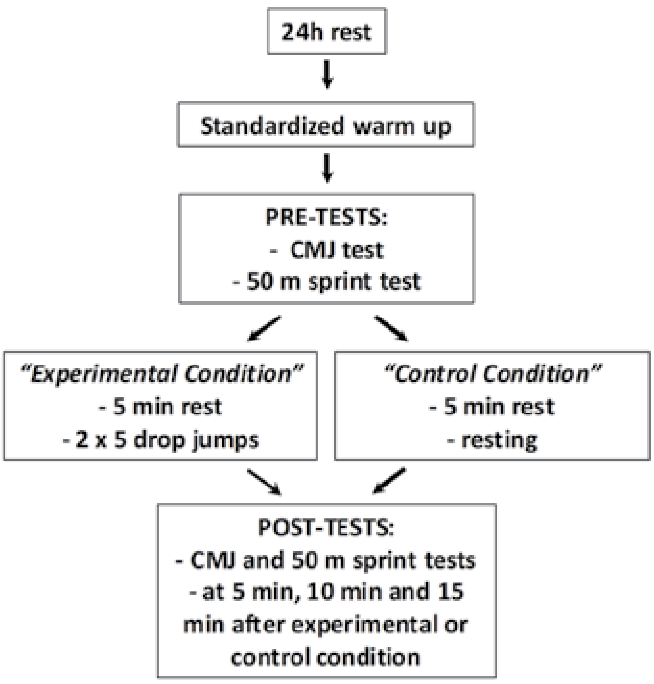


Figure 1. Experimental design of the study

The CMJ test was performed with an initial movement that began with an extended leg position with the trunk in the upright position and the hands placed at the hips. The athletes then performed an excentric-concentric action that finished with a vertical jump. An electronic contact mat platform system (Multisprint, Hidrofit, Brazil) was connected to a computer that was used to measure the vertical jump height based on flight-time [28].

The 50 m sprint time was assessed at an outdoor track, where an infrared timing system (Multisprint, Hidrofit, Brazil) with 0.001 s accuracy was used. The sensors were positioned at 0 m and 50 m of the track to record the beginning and end of the race. The participants started each sprint from a three-point stand position and were instructed to accelerate and run as fast as possible. Wind speed was monitored throughout the entire experiment using a digital portable anemometer (AD-250, Instrutherm, Brazil). All the procedures were performed at the same time of day and the maximum wind speed limit adopted for the experiments was 2.0 m/s, the same benchmark adopted by the IAAF during official outdoor sporting events.

The results were analyzed using statistical software (GraphPad Prism 5®, San Diego, USA). First, the data were submitted to the Shapiro-Wilcox normality test and then analyzed by one-way ANOVA with repeated measures followed by Tukey's multiple comparison post-hoc test. Data were considered significant when p was < 0.05.

Results

The obtained sprint results for both the experimental and control conditions are presented in Table 1 (individual values) and Figure 2 (as mean + standard error of the mean [SEM]). There was a significant difference in the 50 m dash time between the experimental and control conditions at the post-10 and post-15 min intervals (6.361 ± 0.23 s vs. 6.516 ± 0.24 s and 6.299 ± 0.24 s vs 6.468 ± 0.25 s) of –2.4% and –2.7% ($p < 0.05$), respectively. In addition, a significant reduction in the 50 m sprint time was observed in the experimental condition at post-10 and post-15 min by –1.4% and by –2.4% ($p < 0.05$), respectively, when compared to the pre-test (6.452 ± 0.23 s vs 6.361 ± 0.23 s and 6.452 ± 0.23 s vs 6.299 ± 0.24 s) ($p < 0.01$). Sprint time was also decreased in the experimental condition at post-15 min by –1.8% ($p < 0.01$) when compared to the post-5 min interval (6.299 ± 0.08 s vs 6.415 ± 0.07 s).

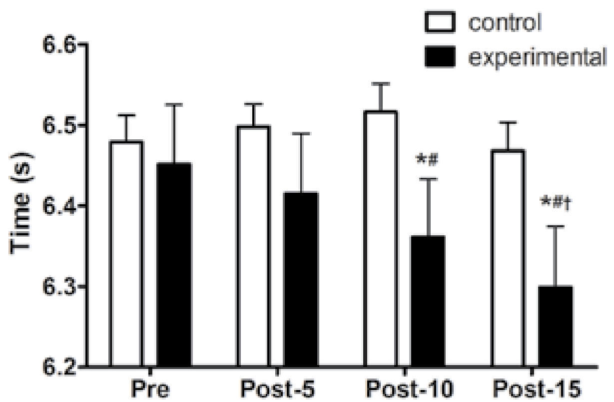
The results of the CMJ height for the experimental and control conditions are presented in Table 2 (individual values) and Figure 3 (mean + SEM). Similarly to sprint performance, the experimental protocol led to a significant increase in CMJ height at post-15 min by +5.5% (45.8 ± 0.66 cm vs 43.4 ± 0.86 cm; $p < 0.01$) when compared to control condition. In addition, the

Table 1. The sprint time of the 50 m dash (in seconds) of the study participants

	Pre-test		Post-5 min		Post-10 min		Post-15 min	
Participant	control	experimental	control	experimental	control	experimental	control	experimental
A	6.443	6.311	6.418	6.427	6.389	6.257	6.365	6.259
B	6.501	6.190	6.486	6.186	6.558	6.177	6.438	6.198
C	6.405	6.447	6.374	6.381	6.474	6.342	6.358	6.151
D	6.452	6.327	6.548	6.411	6.461	6.512	6.422	6.307
E	6.622	6.770	6.651	6.754	6.743	6.690	6.681	6.690
F	6.605	6.829	6.546	6.786	6.599	6.698	6.556	6.698
G	6.252	6.125	6.470	6.001	6.357	5.941	6.387	5.906
H	6.485	6.485	6.475	6.521	6.582	6.312	6.401	6.265
I	6.512	6.421	6.408	6.384	6.464	6.299	6.452	6.208
J	6.516	6.616	6.604	6.299	6.535	6.386	6.620	6.306
mean	6.479	6.452	6.498	6.415	6.516	6.361	6.468	6.299
S.E.M	0.0331	0.0733	0.0280	0.0748	0.0356	0.0725	0.0355	0.0753

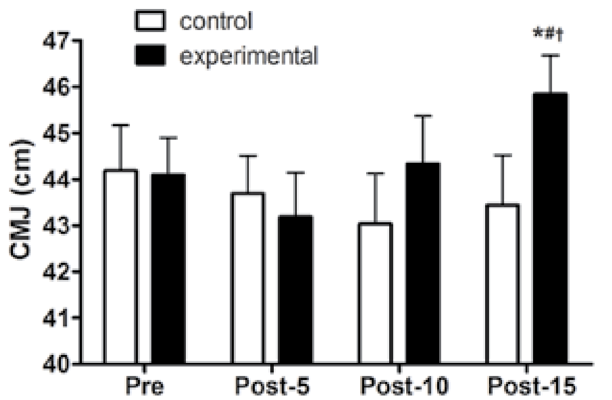
Table 2. The maximal vertical jump height (in cm) of the study participants

	Pre-test		Post-5 min		Post-10 min		Post-15 min	
Participant	control	experimental	control	experimental	control	experimental	control	experimental
A	44.4	43.4	42.6	44	44.2	43	44.1	45.6
B	46.7	46.6	47.6	45.2	45.9	45.6	46.8	47.1
C	42.1	41.4	39.7	39.8	42	40.7	42.5	47.1
D	44	44	43.5	42.9	43.9	43.4	44.5	46.1
E	47.7	43.6	41.5	47.1	47	46.1	49.1	49.3
F	40.4	41.1	39.7	39.8	41.7	39.4	39.8	42.2
G	46.1	46.7	46.2	46.5	46.4	46.3	46.1	47.2
H	44.2	43.9	44.1	43.7	43.2	42.1	43	45.2
I	45.4	45.1	44.9	45.2	45.1	44.2	44.6	45.7
J	40.9	41.1	40.5	40.2	41.4	41.1	42.7	42.9
mean	44.19	44.08	43.69	43.19	43.03	44.32	43.44	45.84
S.E.M	0.770	0.635	0.653	0.754	0.862	0.820	0.860	0.662



* $p < 0.05$ when compared to the control condition at the same moment
\# $p < 0.05$ when compared to the pre-test in the same condition
† $p < 0.01$ when compared to post-5 min of the experimental condition

Figure 2. The sprint time of the 50 m dash. The time was measured at different moments: before preload (Pre), post-5 min (Post-5), post-10 min (Post-10) and post-15 min (Post-15)



* $p < 0.05$ when compared to the control condition at the same moment
\# $p < 0.05$ when compared to the pre-test in the same condition
† $p < 0.01$ when compared to post-5 min of the experimental condition

Figure 3. The maximal vertical jump height. The height was measured at different moments: before preload (Pre), post-5 min (Post-5), post-10 min (Post-10) and post-15 min (Post-15)

CMJ height significantly increased in the experimental condition at post-15 min when compared to the pre-test values by +4% (45.8 ± 0.66 cm vs 44.3 ± 0.63 cm; $p < 0.01$) and post-5 min by +6.1% (45.8 ± 0.84 cm vs 43.2 ± 0.75 cm; $p < 0.001$) in the same (experimental) condition.

Discussion

Muscle PAP is a mechanism by which power twitch is increased after previous conditioning contractions [1, 12, 13]. Since there are various factors involved in PAP induction and since the time of maximal induction has not yet been investigated, this study evaluated the effects of a DJ potentiation protocol on sprint time and CMJ height performance in well-trained athletes at different times. It was found that the DJ potentiation protocol was effective in inducing PAP and improving performance in both the 50 m dash and vertical jump. Sprint time decreased after 10 and 15 min and CMJ height increased after 15 min in the experimental condition (DJ potentiation protocol), suggesting that the time for maximal PAP induction is specific for different high power exercises.

As previously mentioned, strength-exercise induced PAP has been shown to be effective in considerably increasing CMJ height. Young et al. [10] observed an improvement in loaded-CMJ height of 2.8% in athletes 4 min after performing one set of 5 maximal repetitions of squats. Our DJ potentiation protocol induced an increase in CMJ height only at post-15 min. We believe that the difference is due to the design of the experiment. In the Young et al. [10] study, the athletes executed two sets of 5 loaded CMJ (as pre-load), followed by the squat exercise potentiation protocol and finally by one set of 5 loaded-CMJ (post-load). An interval of 4 min between the sets was imposed and the results were compared between pre- and post-load. Thus, PAP induction of this protocol could have resulted from all of the performed exercise and not only from the squat exercise protocol. In fact, the total time between the first pre-load test and post-load test in the Young et al.'s [10] study was 16 min.

As previously discussed, not only is the time interval an important factor for maximal PAP manifestation, but also other factors which are involved in this process. These factors include the design of the potentiation protocol, the type of high power exercise and the experience of the athletes. It is difficult to compare our study to others as these factors vary greatly. PAP manifestation is observed at different time intervals after the potentiation protocols' application in several studies. These post-load time intervals vary between 0.5 min and 20 min [10, 11, 23]. Thus, all these factors need to be considered when potentiation programs are used by athletes that intend to increase muscle power output.

A limited number of studies have investigated the effects of PAP manifestation on sprint time and running speed. When compared to other studies, our DJ potentiation protocol improved sprint time only at the post-10 min and post-15 min intervals. Some studies have found no effect of different potentiation protocols on sprint performance when the individuals were evaluated after a short time of the application (few minutes). Chatzopoulos et al. [25] found that a back half-squat potentiation protocol (10 single repetitions at 90% of 1RM) did not increase running speed post-3 min in a 30 m dash. McBride et al. [21] found that a loaded-CMJ protocol (one set of 3 repetitions) did not improve sprint time post-4 min in a 40 m dash. After the PAP protocols, both potentiation and fatigue could coexist and the balance between these two factors are determinants in the final performance of subsequent high power exercise [1, 26]. Previous studies have shown that a period of 4-5 min is required to restore creatine phosphate and the effectiveness of PAP can be found up to 20 min [10]. Therefore, in our study, the effect of fatigue may have a negative effect on PAP at 5 min after the DJ potentiation protocol.

However, McBride et al. [21] observed an improvement in 40 m sprint time (0.87%) in football players after 4 min of applying one set of 3 repetitions of heavy-loaded squat at 90% of 1RM, but no effect was found when the athletes were submitted to a loaded-CMJ protocol (one set of 3 repetitions) in the same study, demonstrating that the potentiation protocol design is an important factor for PAP manifestation. In our study, we found a decrease (non-significant) of 0.50% in sprint time by DJ potentiation protocol at the post-5 min interval when compared to the pre-test. At post-10 min and post-15 min, the reduction amounted to 1.4% and 2.4%, respectively. As discussed above and observed in our study, the post-load time interval was an important factor for PAP induction. Thus, it is possible that the improvement found by McBride et al. [21] would be higher if the time interval was more prolonged. Moreover, the effect of fatigue can be more pronounced in our design potentiation protocol than in the protocol used by McBride et al. [21].

Conclusion

The results obtained in this study suggest that muscle PAP programs are useful in increasing performance in high power exercises. However, several factors are involved in this process and need to be considered when these programs are used for training track and field athletes. These factors include the design of the potentiation protocol, the time required for maximal induction, the type of high power exercise and the experience of the athletes. The potentiation protocol used in this study (two sets of 5 DJ) is an acute power training method that can be used by coaches and physical trainers in order to improve an athlete's speed in short distances and their performance in vertical jumps when competing. This protocol induced an improvement in 50 m sprint time after 10 min and 15 min and in a countermovement vertical jump after 15 min, demonstrating that the post-load time interval for increasing performance by DJ potentiation protocol in track and field experienced athletes varies according to the type of high power exercise involved. Additional studies are required to evaluate if different DJ potentiation protocols (e.g. different heights of the box for the DJ or the number of sets and drop jumps per set) can be more efficient for improving performance in sprint and CMJ.

In summary, our results suggest that the DJ potentiation protocol used in this study improves performance in sprint time and vertical jump in high performance athletes at different times, suggesting that the peak of PAP induction depends not only on protocol design, but also on the post-loaded time and the high power exercise.

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THE EFFECTS OF MUSCLE ACTIONS UPON STRENGTH GAINS

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ABSTRACT
Purpose. The purpose of this study was to compare the effects of concentric with eccentric muscle actions on strength gains. **Methods.** Forty-two untrained men were randomly divided into three groups: the concentric experimental (CE), the eccentric experimental (EE) and a control (C). The CE group performed only concentric muscle actions at 80% of one repetition maximum (1 RM) and the EE group performed only eccentric muscle actions at 120% of 1 RM. Both groups trained by performing three sets of 10–12 repetitions for eight weeks of biceps curl (BC) and bench press (BP) exercises. The C group did not engage in any type of training. **Results.** Analyses performed within the CE group found that there were significant improvements in muscle strength in the eighth week of BP (Δ% = 26.9%, $p = 0.01$) and in the fourth and eighth week of BC (Δ% = 22.1%, $p = 0.00$ and Δ% = 32.1%, $p = 0.00$, respectively). Analyses of the EE group found that there were significant improvements in muscle strength in the fourth and eighth week of BP (Δ% = 13.7%, $p = 0.00$ and Δ% = 28.4%, $p = 0.00$, respectively). Between the two groups (CE versus EE), comparisons showed that the CE group performed significantly better than the EE group in the fourth and eighth week of BC ($p = 0.00$ and $p = 0.00$, respectively). **Conclusions.** These findings indicate that those who do not train should perform concentric muscle actions in the first 8 weeks of training in order to generate accelerated strength improvement.

Key words: training, exercise, concentric, eccentric, repetition maximum

Introduction

Eccentric muscle actions occur when muscles elongate under tension. Conversely, concentric muscle actions occur when muscles, except for tendon connective tissue [1], undergo shortening while under tension. Acute effects, such as greater tension per motor unit, less energy expenditure, lower electromyographic (EMG) activity, a reduction in the range of joint motion, increased swelling and muscle damage, and delayed onset muscle soreness are well documented and more commonly associated with activities involving eccentric muscle actions than those involving concentric muscle actions [2–5]. However, the more lasting effects, such as increased muscle strength, have yet to be clarified.

A combination of concentric and eccentric muscle actions (the traditional method) is commonly used in resistance training for muscle strength development. Hilliard-Robertson et al. [6] reported that resistance training composed of both eccentric and concentric muscle actions, which largely emphasizes eccentric muscle actions appears to give greater strength gains than when concentric muscle actions are used alone. Corroborating this finding, the American College of Sports Medicine (ACSM) [7] recommends the use of both muscle actions as a combined strategy for increasing maximum strength, power, hypertrophy and muscle endurance. In addition, Dudley et al. [8] show that the omission of eccentric muscle actions compromises strength increase, probably due to the fact that the necessary intensity is not optimal. Furthermore, others studies have also observed that dynamic muscle strength improvements are greatest when eccentric muscle actions are included in training programs [9–11]. Thus, it seems that eccentric muscle actions, when combined with concentric or isolated actions, are indispensable for enhanced muscle strength development.

However, others studies have reported conflicting results, showing no significant difference between the acquired strength gains after performing these two types of muscle actions [12, 13]. Furthermore, it is important to mention another study that compared the strength development of two groups, one of a traditional concentric/eccentric group and the other a solely concentric group. No significant differences were found between the two groups [14], showing that the

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exclusion of eccentric muscle actions does not compromise increased muscle strength.

Given that such isolated concentric or eccentric muscle actions are not commonly used in resistance training of untrained individuals and the lack of certainty regarding the strength gains from concentric or eccentric muscle actions, it is important that their more prolonged effects, such as increased muscle strength, be better understood.

Thus, the purpose of this study was to compare the effects of concentric with eccentric muscle actions on strength gains in untrained men who performed BC and BP exercises over a period of eight weeks. It was hypothesized that after eight weeks of resistance training of the untrained men, concentric muscle actions may provide significant and accelerated increases in muscle strength when compared to eccentric actions.

Material and methods

The study sample was composed of 42 healthy, untrained men who were randomly divided into three groups: the concentric experimental group (CE, n = 14, age = 26.6 ± 2.1 years, height = 176 ± 14 cm, weight = 78 ± 3.9 kg, % body fat = 12.25 ± 2.97%), which used only concentric muscle actions during resistance training; the eccentric experimental group (EE, n = 14, age = 28.2 ± 2.8 years, height = 175 ± 14 cm, weight = 76 ± 4.7 kg, % body fat 13.91 ± 3.33%), which used only eccentric muscle actions and a control group (C, n = 14, age = 27.2 ± 3.3 years, height = 176 ± 14 cm, weight = 77 ± 4.1 kg, % body fat 13.34 ± 3.22%), which did not engage in any type of training.

The following inclusion criteria for the subjects were established: a) no participation in regular physical activity for six months previous to this study; b) a body mass index (BMI) ≤ 25 $Kg \cdot m^{-2}$ to avoid poor fitness levels that could compromise movement execution; c) negative responses on the Physical Activity Readiness Questionnaire (PAR-Q) [15].

The exclusion criteria were: a) use of medication that could influence functional response behavior; b) bone, muscle or joint problems that could limit the execution of the proposed exercises; c) changes in sleep patterns and daily diet.

The subjects signed an informed consent form according to the Declaration of Helsinki and the study was approved by the governing Research Ethics Committee (protocol number 0046/2007).

Pre-training (PRE) data were collected on five different days over a period of 10 days. On the first day, all individuals were subjected to medical history examinations and the anthropometric measurements were taken of body mass, using an electronic scale (Filizola, Brazil), height with a stadiometer (Sanny, Brazil), and percentage body fat using a skinfold caliper (AXF 356, Cescorf, Brazil) as according to the three-side skinfolds protocol [16]. Furthermore, the subjects were familiarized with the BP and BC exercises using concentric muscle actions in the CE group and eccentric muscle actions in the EE group. On the second and third day, each 48 hours apart, all of the subjects underwent two more familiarization sessions for the same exercises.

On the fourth day, 48 hours after the third familiarization session, all subjects were submitted to 1 RM testing of both BP and BC. 1 RM was defined as the maximum amount of weight that can be lifted one time with proper technique through a full range of motion [17]. For the BP, the subjects were positioned on the bench with both feet flat on the floor, starting the movement with elbows fully extended and the shoulders in a horizontal flexion. They performed an elbow flexion until the bar touched the hand of one researcher, experienced in resistance training, who was positioned beside the subject (see Fig. 1), with the subject then returning to the starting position. For the BC, the subjects sat on a bench, initiating the movement with their forearms touching the trestle positioned in front of the bench (see Fig. 2), performing a full elbow flexion and then returning to the initial position.

Figure 1. The position used when performing the BP

Figure 2. The position used when performing BC

On the fifth day, 48 hours after determining 1 RM, the subjects were re-tested to obtain load reproducibility. The highest of the two values found on the two test days was considered the subject's 1 RM, with a negligible difference of 5%. If the difference was greater than 5%, the test was performed again to define the ideal load. Subjects were not allowed to engage in any exercise between the test sessions in order to avoid any interference with the results. Moreover, the 1 RM tests and re-tests were performed once again at the end of the fourth and eighth week.

To minimize possible errors with the 1 RM test and re-testing, the following strategies as prescribed by Simão et al. [18] were implemented: a) all of the subjects received standardized instruction on data assessment and the exercise technique before testing; b) the exercise technique was monitored and corrected as needed; c) all subjects received verbal encouragement during testing; d) and the weight of all the weight plates and bars used was determined with a precision scale. The rest interval was about five minutes between each exercise attempt and 10 minutes between the different exercises. The maximum number of attempts for each exercise was three. If a subject did not achieve 1 RM in these three attempts, they were asked to perform another 1 RM test session.

On the sixth day, 48 to 72 hours after the 1 RM testing process, the CE and EE groups were submitted to the first of their 16 training sessions, which occurred twice a week over a period of eight weeks. Before initiating the exercises, the subjects performed a warm-up consisting of 10 repetitions at 40% of 1 RM for the CE group and 80% of 1 RM for the EE group for both BP and BC. The CE group's warm-up involved only concentric muscle actions while only eccentric muscle actions for the EE group. A two-minute rest interval was allowed between the warm-up and the assigned training exercise.

To establish the training load of the subjects in the EE group, 20% was added to their 1 RM load [12]. This addition was necessary so that during the eccentric muscle actions the subjects could not resist or avoid stretching. Conversely, 20% was deducted from the 1 RM load of the CE subjects. This deduction was necessary so that during the concentric muscle actions the subjects could perform the number of repetitions required during training, as it would not be possible perform 10–12 repetitions of 100% of 1 RM.

After the warm-up session, the subjects of the CE group performed three sets of 10–12 repetitions with concentric muscle actions at 80% of 1 RM while those in the EE group performed three sets of 10–12 repetitions with eccentric muscle actions at 120% of 1 RM, for both exercises. When the subjects were able to perform 12 repetitions without muscle fatigue (failure) during the three sets of each exercise with the prescribed load, the training load was then increased by 10% of 1 RM.

The rest interval between the sets and exercises was three minutes [19, 20]. The velocity of movement was controlled with a digital stopwatch (HS-30W, Casio, Japan), with three seconds given for each muscle action (concentric or eccentric) totaling 30 seconds under tension for each set of 10 repetitions. The subjects returned to the initial position as soon as possible after each muscle action without being subjected to overload. Two experienced resistance training researchers ensured that the correct technique was followed and the prescribed training load was met.

During training, concentric muscle actions were performed as follows: for the BP, one of the researchers placed the bar into the hands of the subject while it was being held by the other researcher who was positioned beside the subject (initial position). A concentric muscle action was performed and the bar was removed from the subject hands when his elbows were completely extended (final position). For the BC, the bar was handed to the subject whose forearms rested on a pad found in front of the bench (initial position). A concentric muscle action was performed and the bar was removed from the subject's hands when his elbows were fully flexed (final position).

During training, eccentric muscle actions were performed as follows: for the BP, a researcher placed the bar into the hands of the subject while his elbows were completely extended (initial position). An eccentric muscle action was performed and the bar was removed from the subjects hands when it touched the hand of the researcher who was positioned beside the subject (final position). For the BC, the bar was handed to the subject when his elbows were fully flexed (initial position). An eccentric muscle action was performed and the bar was removed from the subject's hands when his forearms touched the pad (final position).

The data collected are presented as mean ± SD. The Levene test was used to verify the homogeneity of variance. Once homogeneity was confirmed, a mixed model ANOVA (the group [CE, EE, C] x testing time [PRE, fourth, eighth week]) was conducted to compare the results within and across the groups for both exercises. The Tukey post-hoc test was used to identify significant difference [21]. Statistical software was used for all analyses (Statsoft Version 5.5, Statsoft, USA) and a level of 0.05 was used to determine significance.

Results

Comparisons performed within the CE group showed significant improvements in muscle strength in the eighth week of performing the BP exercise ($\Delta\%$ = 26.9%, $p = 0.01$) and in the fourth and eighth week of performing the BC exercise ($\Delta\%$ = 22.1%, $p = 0.00$ and $\Delta\%$ = 32.1%, $p = 0.00$, respectively) when compared to the PRE data. Comparisons made within the EE group revealed significant improvements in muscle

Table 1. 1 RM tests at PRE, the fourth and then eighth week of resistance training

	1 RM bench press (kg)			1 RM biceps curl (kg)		
Groups	PRE	4 weeks	8 weeks	PRE	4 weeks	8 weeks
CE (*n* = 14)	65.7 (15.0)	75.7 (10.8)†	80.5 (4.01)*†	32.8 (5.01)	39.4 (3.37)*†‡	42.5 (3.18)*†‡
EE (*n* = 14)	63.8 (1.65)	72.0 (4.43)*	80.4 (4.01)*†	30.2 (6.51)	32.0 (6.57)	36.0 (7.69)
C (*n* = 14)	66.8 (7.47)	67.0 (7.30)	69.4 (7.93)	31.7 (2.81)	32.0 (3.33)	33.4 (2.98)

Data are expressed as mean (SD).
1 RM = One repetition maximum
PRE = Pretraining
Kg = Kilogram
CE = Concentric Experimental Group
EE = Eccentric Experimental Group
C = Control Group

* significant difference ($p < 0.05$) from PRE data
† significant difference ($p < 0.05$) from the C group
‡ significant difference ($p < 0.05$) from the EE group

strength in the fourth and eighth week of the BP exercise (Δ% = 13.7%, $p = 0.00$ and Δ% = 28.4%, $p = 0.00$, respectively) when compared to the PRE data. As expected, no significant differences were demonstrated within the C group. Across-group comparisons revealed significant improvements in muscle strength in the CE group in the fourth and eighth week compared with the fourth and eighth week in the C group for both exercises: for BP ($p = 0.01$ and $p = 0.00$, respectively), and for BC ($p = 0.00$ and $p = 0.00$, respectively). When comparing the EE and C groups, only in the eighth week of BP were significant improvements found in muscle strength in the EE group ($p = 0.00$). In comparisons between the CE and EE groups, the strength gain of the CE group was significantly higher than in the EE group in the fourth and eighth week of BC ($p = 0.00$ and $p = 0.00$, respectively). However, the difference was not significant in the fourth and eighth week of BP (see Tab. 1).

Discussion

It was hypothesized that in the eight weeks of training, concentric muscle actions could result in significant and accelerated strength gains than when compared to eccentric muscle actions in the group of untrained individuals. To test this hypothesis, the participants of this study were trained and tested in two exercises. In the first exercise (BC), the CE group performed better than the EE group, while the strength gain was similar in the second exercise (BP). As such, the results of the across-group comparisons (CE vs. EE) confirm the stated hypothesis.

However, the confirmation of the stated hypothesis is in direct contrast to previous studies [11, 22, 23]. Kaminski et al. [11] compared strength gains between eccentric and concentric muscle actions involving the hamstring muscles of trained subjects. They reported that the group performing eccentric muscle actions improved by 29%, while the group using concentric muscle actions showed only 19% improvement. In another study, Hollander et al. [22] demonstrated that eccentric muscle actions resulted in greater strength gains than concentric muscle actions in six exercises tested in men with resistance training experience. Furthermore, Vikne et al. [23] compared the effects of concentric and eccentric muscle actions on muscle strength of trained subjects. They also concluded that eccentric muscle actions led to greater strength increases than concentric muscle actions (with eccentric 26% > concentric 9%).

The discrepancy between, for example, the BC results in this study and those obtained by Kaminski et al. [11], Hollander et al. [22] and Vikne et al. [23] may be due to the fact that they studied trained subjects. In this study only untrained subjects were analyzed, and it seems that neural factors account for the larger initial strength increase in the first weeks of training [24]. In addition, Fang et al. [25] revealed that detailed comparisons of EMG signals suggest that eccentric muscle actions require a significantly longer time for early preparation and a significantly greater magnitude of cortical activity for later movement execution. Furthermore, during eccentric muscle actions, fewer motors units are recruited than in concentric actions [26]. This suggests less total muscle activity which in turn suggests lower neural adaptation. Higbie et al. [27] concluded that total muscle activity (EMG activity) during eccentric muscle actions was less than in concentric muscle actions before training. The similar result between EMG activity in pre- and post-training during concentric and eccentric muscle actions suggests that the neural adaptation of eccentric muscle actions was still less even after 10 weeks of training.

Therefore, it seems that in the beginning of a training period for untrained individuals, eccentric muscle actions show greater neural inhibition (i.e., reduced neuromuscular activation), but would later decrease with continued training [28]. Thus, it is likely that the longer preparation time needed for eccentric muscle actions [25], associated with greater neural inhibition [27], delayed strength evolution thereby contributing to the lower strength gains observed in the EE group after BC.

By contrast, the strength gain obtained in BP by the CE and EE groups was similar. However, this team suggests that the BP exercise was favored by the isometric contraction of the pectoralis muscle, a fact observed during the BC exercises performed by the EE group. Babault et al. [29] reported that the neural drive (the number of motor units or their discharge rate) during eccentric muscle actions is lower than during isometric contraction. This suggests that isometric contractions, unlike eccentric muscle actions, show lower neural inhibition and higher muscle activity. Therefore, the impossibility of excluding the isometric contractions and their high muscle activity avoided delaying the strength gain obtained by the EE group in BP, and contributed to the similar findings obtained by the CE group in the same exercise. However, the results of the abovementioned studies [27, 28] suggest that if this experiment had been carried out for more than eight weeks (i.e.; 10, 12, 14, or more weeks), the results would have been different, that is, the EE group would likely have performed significantly better than CE group in both exercises (BC and BP).

The weakness of this study may be the lack of specificity between the muscle actions used and the tests performed (1 RM). Higbie et al. [27] analyzed the effects of eccentric versus concentric unilateral knee extension training on strength gains in women. After 10 weeks, they concluded that the concentric muscle action group performed better in concentric specifics tests, while the group using eccentric muscle actions exhibited enhanced performance in specific eccentric tests.

Conclusion

This study makes an important contribution to the available literature in this subject. After eight weeks of training, concentric muscle actions resulted in significant and accelerated strength gains in untrained men when compared to eccentric muscle actions. Therefore, since the original stated hypothesis was confirmed, it can be concluded that concentric muscle actions should be used in the first eight weeks of training of untrained individuals to generate accelerated strength improvement. By contrast, eccentric muscle actions should be excluded to avoid any possible delayed effects. However, new studies are needed to evaluate if only single-joint or only multi-joint exercises show the same response to different types of muscle actions. Tests must also be applied singly (more specific) to better elucidate the existing discrepancies. Moreover, longer training periods (more than eight weeks) should also be used to confirm the delayed effects of isolated eccentric muscle actions in the first eight weeks of training of untrained individuals.

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DYNAMICAL ASYMMETRY OF UPPER-LIMB MOVEMENTS DURING SWIMMING

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ABSTRACT
Purpose. This study aimed at introducing a method towards determining the dynamical asymmetry of the upper extremities during swimming and to find its relationship with lower-limb movements in children when swimming the breaststroke. **Methods.** Twenty boys participated in the research, where seven boys were found to perform incorrect lower-limb movements when swimming. Therefore, the subjects were divided into two groups, those who maintained correct lower-limb movements when swimming and those who did not. The subjects swam for short distances using either only their upper limbs or both upper and lower limbs. The water pressure that was exerted on the right and left hand of the subject was recorded for both tests. On the basis of the compiled data, the upper-limb movements' asymmetry index was calculated. **Results.** Incorrect lower extremity movements when performing the breaststroke resulted in increased upper-limb dynamical asymmetry. **Conclusion.** The method applied in this study enables one to diagnosis the dynamical asymmetry of upper-limb movements when swimming. Altogether, it was found in the examined group that incorrect lower-limb movements in the breaststroke did not decrease swimming efficiency. However, an increase of the upper extremities' dynamical asymmetry might have decreased the efficiency of the shoulder-girdle muscles' symmetrization. In the case of individuals performing incorrect lower-limb movements in the breaststroke, it is recommended to improve their performance or to swim with the upper limbs only.

Key words: symmetrization, pressure sensors, augmented feedback, therapy

Introduction

The results of research conducted on primary school children are alarming, where the great majority of children are found to display abnormal or incorrect body postures. The number of afflicted children only increases in later school years and can be mainly observed in boys [1, 2]. This occurrence is frequently related to lifestyle diseases, an increased lack of physical activity and incorrect sitting posture [1, 3]. It is also connected with a lack of knowledge about preventive treatments for body posture as well as the effect of pre-pubertal acceleration [4]. Only early prevention, quick diagnosis and suitable corrective treatment may lead to a decrease of this trend. Corrective treatment largely consists of specific exercise, where symmetrical exercises are usually recommended to individuals with scoliotic posture [3], while asymmetrical exercises are used in treating scoliosis [5]. Although many of the suggested exercises are performed in a gym, swimming has been found to enrich such corrective treatments, not only as a form of physical activity, but its increasingly larger role in the prevention and correction of body posture [3, 6]. Water, thanks to its natural properties, such as it having a higher density than air as well as providing buoyancy and increased resistance force (its value increases with velocity squared) provides ideal conditions for such treatment. Contrary to land-based activities, swimming allows a subject's position to be horizontal, allowing the spine to be unloaded. The main form of propulsion is provided by the upper extremities [7, 8], allowing the spine to be correctly shaped by exercising the muscles of the upper extremities [9]. In this case one very suitable form of swimming is the breaststroke (and its varieties), which can be considered to be a type of symmetrical physical activity [10], and, as such, may be applied in providing treatment for scoliotic body posture. However, one aspect that needs clarification is the frequently observed asymmetrical movements of the lower extremities in the breaststroke [11–13], which may disturb the proper performance of the upper limbs. Such an issue may not even be considered when providing therapeutic treatment, and unfortunately, the recommendation of different types of corrective exercises without detailed knowledge of the disparities that may exist in them can be problematic. This intuitive way of selecting exercises for therapeutic treatment may be even inefficient or harmful. Although there are many methods for monitoring the results of such therapy (such as x-ray, MRI, photogrammetry, etc.), they are unfortunately expensive and most of them are able to provide only long-term diagnoses [14–16]. In addition, their application is usually limited to land-

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based activities [17]. Therefore, there is a need to have a tool that is capable of providing objective information on the performance of providing breaststroke swimming as a form of treatment [18]. The research found in this paper aims at introducing a method that can be applied to determining the dynamical asymmetry of the upper extremities during swimming and in finding the relation of these values with the lower limbs movements when performing the breaststroke, especially in regard to children.

Material and methods

Twenty 11-year-old boys participated in the study. As primary schools provide swimming lessons for children from the 1st to 3rd grade, it was decided to include only boys who had finished the 3rd grade. Each subject was informed about the experiment and the boys' parents provided written consent. In addition, approval for the experiment was given by the University's Senate Committee for the Ethics of Scientific Research. The experiment was conducted at the Research Laboratory on Human Movement in a Natural Environment at the University School of Physical Education of Wroclaw, which received a Certificate of Quality Management System and fulfills the requirements of PN-EN ISO 9001:2001.

As was mentioned, twenty 11-year-old boys participated in the study. The subjects' anthropometric features were measured, including age, body mass and body height, finding the examined subjects to be almost nearly homogenous (Tab. 1). During initial water trials, seven of the subjects displayed incorrect (asymmetrical) lower limbs movements when swimming. As such, the twenty boys were then divided into two groups, the first (I) showing correct (symmetrical) lower-limb movements and the second (II) showing incorrect (asymmetrical) lower-limb movements.

The hand's surface is the most important source of propulsion provided by the upper limbs during swimming [19]. Its trajectory and attack angle determines the propulsion's force [20]. However, this force is not generated by pressure created by the water on the palm, but by its pressure differential between the palmar and dorsal side of the hand [8, 19]. To measure propulsion two 26 PCB type 5 (Honeywell, USA), connected to a computer, were used. The sensors were placed between the third and fourth finger of both the right and left hand to measure the difference of water pressure exerted on the back and on the palm of each hand. Prior to measurement the pressure sensors were calibrated by signal measurement at depths of 0, 20, 40, 60, 80 and 100 cm. In addition, the pressure sensors were calibrated with normal atmospheric pressure as a reference. The immersion depth of the sensor did not influence the signal level.

The task of the subjects was to swim 15 m in the shortest possible time. The participants each started from a vertical position without pushing off from the wall or swimming pool bottom. The first test was to swim the breaststroke using both the upper and lower limbs (this test was named UL+LL). After a period of rest, the test was repeated. This time, a pull buoy was placed between the lower limbs which immobilized the legs and prevented them from being used as a source of propulsion. The subjects then swam the breaststroke using only their upper limbs (UL). The time to complete the distance and the difference of pressure for the right and left hand were recorded. The signal was sampled at a frequency of 100 Hz. The recorded signals were filtered by a 4th Order Butterworth Filter Stage at a 12 Hz cutoff frequency. The propulsion phases from the 6th to the 10th cycles of both tests were then analyzed. It was assumed that the upper limbs' propulsion phase started once the difference of pressure is positive for the first upper limb to enter the water, while the end of the phase reflected the last positive value of the measured pressure difference from the second limb (Fig. 1).

On the basis of Vagenas and Hoshizaki's [21] correlation analysis, their formula was modified to fit the needs of calculating the asymmetry coefficient of the upper-limb movements propulsion phase, as:

Table 1. The characteristics of the research subjects (means ± standard deviation)

	Group	
	I (*N* = 13)	II (*N* = 7)
Age (years)	11.1 ± 0.3	10.9 ± 0.2
Body mass (kg)	42.7 ± 6.4	40.0 ± 7.7
Body height (cm)	153.0 ± 4.4	149.0 ± 8.2
$t_{15\,m}$ UL+LL (s)	14.2 ± 0.7	14.2 ± 1.2
$t_{15\,m}$ UL (s)	19.3 ± 1.8	19.0 ± 1.7

Group I – correct (symmetrical) lower-limb movement
Group II – incorrect (asymmetrical) lower-limb movement
$t_{15\,m}$ UL+LL – 15 m swimming time using both upper and lower limbs
$t_{15\,m}$ UL – 15 m swimming time using only upper limbs

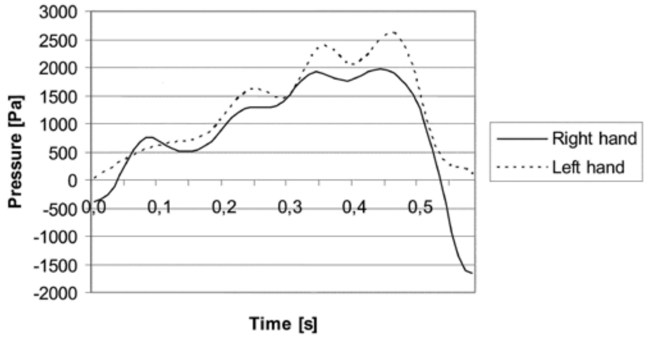


Figure 1. An example of the propulsion phase

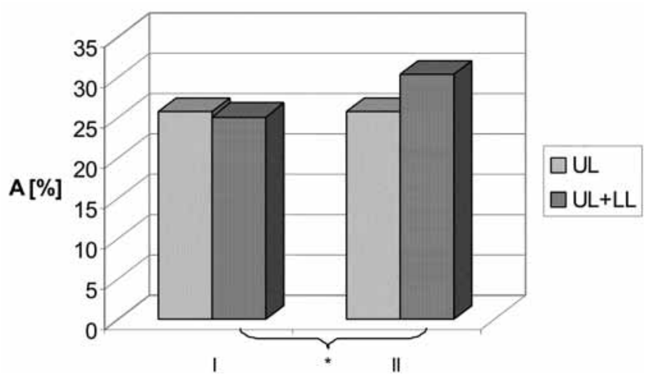
$$A = \frac{|P_R - P_L|}{2 \cdot max(|P_R|,|P_L|)} \cdot 100\% \qquad (1)$$

where P_R and P_L are the values of the pressure differential for the right and left hand, respectively. The numerator corresponds to the modulus of the P_R and P_L difference. The denominator represents the modulus of the highest time sample value between P_R or P_L multiplied by two. When $A = 0\%$, the hand movements is symmetrical ($P_R = P_L$ and $P_R > 0$ and $P_L > 0$). Positive asymmetry is assessed when $0\% < A < 50\%$ ($P_R > 0$ and $P_L > 0$ and $P_R \neq P_L$). $A = 50\%$ represents border asymmetry, where one limb has a pressure differential of 0 ($P_R = 0$ and $P_L > 0$ or $P_L = 0$ and $P_R > 0$). For $50\% < A < 100\%$ there is negative asymmetry ($P_R > 0$ and $P_L < 0$ or $P_R < 0$ and $P_L > 0$). $A = 100\%$ represents full asymmetry of the hand movements ($P_R = -P_L$).

The mean asymmetry coefficient for each subject was then determined and the results were checked by seeing if the requirements of using a parametric test were fulfilled. The Shapiro-Wilk test was applied to determine the normality of the variables' distribution. The homogeneity of variations was verified by using the Levene test. The influence of the lower limbs on upper-limb movement symmetry was verified by an analysis of variations with repetitions and Fischer's post-hoc test. The level of statistical significance was set as $p < 0.05$.

Results

When only the upper limbs propelled the body, the participants of both groups obtained the same dynamical asymmetry values (Fig. 2). However, the results from both groups were significantly different once the lower limbs were used as a second source of propulsion. The usage of the lower limbs of group I, using the correct movements, did not result in upper-limb movement asymmetry, while the incorrect lower-limb movements of group II reflected in an increase in upper-limb movement asymmetry. ANOVA results revealed that the greatest influence on the dynamical asymmetry of the upper limbs could be influenced by two factors: the amount of propulsion and the type of movements performed by the lower extremities ($p = 0.11$). The influence of these two separate factors was $p = 0.22$ and $p = 0.17$, respectively.



Group I – correct (symmetrical) lower limbs movement
Group II – incorrect (asymmetrical) lower limbs movement
* a significance level of $p < 0.05$

Figure 2. Asymmetry of the upper extremities during the breaststroke: using only upper limbs (UL) and using both upper and lower limbs (UL+LL)

Discussion

This study aimed at introducing a method towards determining the dynamical asymmetry of the upper extremities and to find its relationship with lower-limb movements in children when performing the breaststroke. Although the examined subjects were nearly homogenous, the key difference found among them was the quality of the lower-limb movements when performing the breaststroke. As such, one group presented asymmetrical leg movements while the other showed symmetrical lower-limb movements. It may seem that asymmetrical lower-limb movements, considered as incorrect, should lower the performance capacity of the subjects. However, the time required to swim the 15 m distance for both groups was identical when both the upper and lower extremities were used as a source of propulsion. Hence, such a statement cannot be made.

Nonetheless, it was observed that incorrect lower-limb movements negatively influenced upper-limb movements due to an increase in dynamical asymmetry. It should be noted that lower limb movement asymmetry when swimming the breaststroke is largely understood as incorrect through the rules of International Swimming Federation (FINA, Fédération Internationale de Natation) [22]. There were several attempts to explain the origin of how this asymmetry came about [11–13]. The results obtained indicate that the correctness of the lower extremities' movements in the breaststroke should also be perceived through its coordination with the upper extremities' movements. This is because the human body is a biokinematic chain of linked components which mutually interact [23]. Errors, specifically asymmetric movements, created by the lower extremities may negatively influence the performance of the upper extremities. Their influence on the muscle system's development may be different and depend on the degree of congruity within such a pattern. The results obtained in this study question the usage of the breaststroke with asymmetric movements of the lower extremities as a measure to symmetrize the muscles of the shoulder girdle. Unequally shaped shoulder girdle muscles disturb spine mechanics and have a poor effect on their statics [24]. An incorrect, long-lasting load of this kind may cause maladaptation and structural changes in the spine area [25]. From a mechanical view-point, providing a balanced load is a necessary aspect in the case of providing corrective treatment to the spine. Therefore, a careless application of competitive swimming strokes for body posture correction may create disadvantageous effects [26–28]. Some recommendations that consider modifying the usage of competitive swimming strokes for therapy can be found in literature [3, 29]. However, none of them are supported by any objective forms of data. For example, such attempts were made by Iwanowski and Fecica [26], but the limited amount of collected data was caused by a lack of tools which could be applied in water [17]. The conditions of a water environment make it difficult, even impossible, to properly adjust diagnostic methods that are used on land. Therefore, it is important to build a valid, user-friendly and low-cost assessment tool that is adequate in diagnosing the effectiveness of swimming therapy. It is hoped that the presented method in this study meets these requirements. Moreover, this method is not harmful to the tested subjects and can be applied at each stage of therapy. In addition, the obtained results facilitate archiving and enable one to make comparisons with the recorded data. The data on the performance of the limbs' movements give the ability to quantitatively assess as well as conduct modifications of treatment, allowing for an individual approach to a subject. Such augmented feedback increases performance [30] and the motivation of participants [31]. Moreover, faster feedback yields improvement and reduces the duration of therapy [32]. However, upon completing treatment for postural defects, other, more sophisticated methods (X-ray, photogrammetry, etc.) should be used to assess the final results. In addition, one limitation of the presented method is the focus on causes of movement, e.g., the forces. Hence, in order to obtain a more complete account of the movements, future studies should include video recording.

Conclusion

1. The applied method allows for diagnosis of dynamical asymmetry present in upper limbs movements during swimming.

2. Incorrect lower limb movements in the breaststroke did not decrease sports efficiency of the examined group. However, an increase of the upper extremities' dynamical asymmetry might have decreased the efficiency of the shoulder girdle muscles' symmetrization.

3. In the case of incorrect lower limb movements present in the breaststroke, it is recommended to improve their performance or to swim using the upper limbs only.

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ANAEROBIC POWER ACROSS ADOLESCENCE IN SOCCER PLAYERS

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ABSTRACT
Purpose. Although the contribution of anaerobic power in soccer performance is recognized, this component of physical fitness is not well-studied in adolescent players. The aim of this study is to investigate the development of anaerobic power across adolescence in a laboratory setting. **Methods.** Male adolescents (N = 217; aged 12.01–20.98 y), classified into nine one-year age-groups, and adult players (as the control group, N = 29; aged 21.01–31.59 y), who were all members of competitive soccer clubs, performed the 30-s Wingate anaerobic test (WAnT) against a braking force of 0.075 $Kg \cdot Kg^{-1}$ of body mass. **Results.** Compared with previous age-matched studies on the general population, the participants exhibited superior WAnT scores. The Pearson moment correlation coefficient between age and peak power (P_{peak}) was $r = 0.71$ ($p < 0.001$) and between age and mean power (P_{mean}) $r = 0.75$ ($p < 0.001$). Even when body mass or fat free mass was taken into account, the effect of age on these parameters remained ($0.51 < r < 0.55$, $p < 0.001$). One-way analysis of variance revealed differences in anaerobic power between the age groups across adolescence ($p < 0.001$), with the adult and age groups in the higher spectrum of adolescence performing better than those in the lower spectrum, supporting the aforementioned findings. **Conclusions.** We confirmed the importance of short-term power in adolescent soccer players, as well as the strong association between this sport-related physical fitness parameter and body mass and fat free mass ($0.89 < r < 0.94$, $p < 0.001$). However, what is novel is that we demonstrated that age effect on P_{peak} and P_{mean} remained even when body mass and fat free mass were factored out.

Key words: adolescent, physical fitness, exercise test, soccer, growth

Introduction

Performance in soccer results from a combination of physiological, psychological, social and environmental factors. Among the physiological factors, both physical fitness and the metabolic demands of game play have been well-studied in elite adult players, although recently there is an increased scientific interest in the physiological predisposition of young players for future excellence [1]. In spite of the popularity of soccer in adolescence and the foundation of several professional schools for young players, few studies have been published regarding physiological characteristics and, in particular, the anaerobic power of these athletes [2, 3]. Aerobic capacity is necessary to maintain performance during the 90 min of a soccer game, to undertake demanding training and to achieve optimal recovery; on the other hand, anaerobic metabolic pathways are utilized during very short bursts of moderate to intensive effort that can directly determine a match's outcome. When comparing the activity patterns during match play between adult and young players, not many differences can be found [4]. However, the physical and physiological characteristics of young athletes are influenced by body development and, consequently, they may be different from those of their adult counterparts [5, 6].

Due to inherent ethical and methodological issues about the direct assessment of anaerobic metabolism in adolescents, the employment of alternative non-invasive methods targeting mechanical short-term power output was suggested by Van Praagh and Doré [7]. Detailed information about one's anaerobic power can be obtained by valid and reliable laboratory methods, such as the Wingate 30-s anaerobic test (WAnT) [8], the Bosco 60-s test [9] and the Force-velocity (F-v) test [10]. Compared with the other tests, WAnT has the advantage in that it provides information about both the alactic and lactic anaerobic energy transfer system. The main indices of this test are: a) peak power (P_{peak}), the highest power elicited during the test taken as the average power of any 5-s period; b) mean power (P_{mean}), the average power during the 30-s test, minimal power; and c) fatigue index (FI), the difference between P_{peak} and minimal power (P_{min}), divided by P_{peak}. Regarding the taxation of the human energy transfer systems during the test, P_{peak} is considered as a descriptor of short-term power that relies mainly upon adenosine triphosphate-creatine phosphate (alactic anaerobic system), and P_{mean} as a descriptor of local muscular endurance capacity that relies mainly upon anaerobic glycolysis resulting in lactate production (lactic anaerobic system).

Previous studies employing the WAnT, conducted on female soccer players, revealed that starters had better peak power than substitutes [11], indicating a link between this test and soccer performance. Knowledge about one's power characteristics can provide important information for optimal sports training, as the athlete can concentrate on their "weak" component of power, i.e. peak, mean or fatigue index. On the other hand, fitness specialists working with young soccer players should take the differences of these characteristics between adult and adolescent players into account, and the quantification of such differences could help either in talent identification or in improvement of overall power.

The development of maximal anaerobic power across adolescence has already been investigated either in the male general population (*N* = 184, aged 11–17 y) [12] or in soccer players (*N* = 328, aged 11–18 y) [2] with the employment of field methods (vertical jump, 40-m sprint) and cross-sectional studies. It has been also studied by laboratory methods (Force-velocity test and WAnT) in the general population, in the lower spectrum of adolescence (*N* = 81, aged 11–15 y) [13], on boys aged 8–18 y (*N* = 150) [14] and on males aged 10–45 y (*N* = 300) [15]. WAnT has been employed in research on adolescent soccer players to study the physiological profile of US Olympic youth soccer athletes [3], and to compare anaerobic fitness and repeated sprint tests [16]. However, a comprehensive, sport-specific investigation through the WAnT in a large sample would aid in more clearly defining the present levels of anaerobic power across adolescence.

To sum up, relevant previous studies were carried out either in large samples of the general population employing laboratory methods or in large samples of soccer players using field methods or in small samples of soccer players employing laboratory methods. Therefore, in the present study, we have examined the anaerobic power of young male soccer players with the WAnT. Our goal is to test two related hypotheses: 1) there are no differences with regard to WAnT indices between the age-groups of participants; and 2) there is no association between age and the WAnT indices.

Material and methods

In this investigation, a non-experimental, descriptive-correlation design was used to examine the effect of age on anaerobic power across adolescence. The testing procedures were performed during the competition season of 2009–2010. The local Institutional Review Board approved the study, and oral and written informed consent was received from all players or parents after verbal explanation of the experimental design and potential risks of the study. Exclusion criteria included any history of chronic medical conditions and the use of any medication. The male adolescents (*N* = 217; aged 12.01–20.98 y), classified into nine one-year age-groups (those under thirteen were classified as U13 as well as aged 12.01–13 y; U14: 13.01–14 y, U15: 14.01–15 y, U16: 15.01–16 y, U17: 16.01–17 y, U18: 17.01–18 y, U19: 18.01–19 y, U20: 19.01–20 y, U21: 20.01–21 y) and adult players (classified as a control group, *N* = 29; aged 21.01–31.59 y) who volunteered to participate in this study were all members of competitive soccer clubs (Tab. 1). Although the adolescence period is difficult to define in terms of chronological age due to its variation in onset time and termination, it is suggested to range between 10 and 22 y in boys [17] and is considered to be the cornerstone for future athletic excellence. The players were familiarized with the testing procedures used in this study through pre-investigation familiarization sessions. The study participants visited our laboratory once, where anthropometric and body composition data were obtained, followed by a guided 15-min warm-up and then the WAnT was performed.

Table 1. Anthropometric characteristics and the body composition of the study participants

	Age groups									
	U13	U14	U15	U16	U17	U18	U19	U20	U21	Control
N	15	28	43	35	25	29	12	17	13	29
Age (y)	12.67 (0.27)	13.5 (0.24)	14.53 (0.27)	15.51 (0.29)	16.51 (0.29)	17.44 (0.26)	18.29 (0.21)	19.49 (0.35)	20.59 (0.26)	25.28 (3.11)
Body mass (kg)	47.6 (10.4)	58.3 (7.2)	61 (8.8)	66.3 (9.5)	73.2 (14.1)	68.5 (9.6)	69.9 (5.6)	73.8 (6.3)	75.6 (6.8)	76.3 (6.5)
Stature (m)	1.561 (0.112)	1.666 (0.074)	1.702 (0.08)	1.734 (0.057)	1.759 (0.061)	1.748 (0.053)	1.752 (0.056)	1.773 (0.062)	1.78 (0.065)	1.795 (0.059)
BMI (kg · m^{-2})	19.27 (1.89)	20.97 (1.98)	21.04 (2.49)	22.01 (2.68)	23.67 (4.63)	22.35 (2.56)	22.76 (0.99)	23.5 (1.78)	23.84 (1.46)	23.66 (1.25)
Body fat (%)	14.6 (3.6)	16.4 (3.6)	16 (4)	16.4 (4.2)	16.4 (4.7)	15.4 (3.2)	14.7 (3)	14.9 (3.2)	14.4 (2)	14.9 (3)
Fat-free mass (kg)	40.5 (8.2)	48.6 (5.7)	51.1 (6.6)	55.1 (6.1)	60.7 (8.5)	57.7 (6.8)	59.7 (5.3)	62.7 (4.1)	64.6 (5.5)	64.9 (5)

Values are presented as mean with standard deviation in brackets. BMI – body mass index

Stature, body mass and ten skinfold sites were measured and the body mass index was calculated as well as the percentage of body fat was estimated from the sum of the skinfold measurements [18]. Fat free mass was calculated as the difference between body mass and the product of body mass by the percentage of body fat. Skinfold measurements were taken on the dominant side of each athlete. An electronic weight scale (HD-351, Tanita, USA) was employed for body mass measurement (to the nearest 0.1 kg), a portable stadiometer (SECA, UK) for stature (0.001 m) and a caliper (Harpenden, UK) for skinfolds (0.0005 m). After the taking to the above anthropometric measurements and a short warm-up, all of the athletes completed the WAnT for the lower limbs on a cycle ergometer (Ergomedic 874, Monark, Sweden). Braking force for the 30-sec WAnT was determined by the product of body mass in kg by 0.075. Seat height was adjusted to each participant's satisfaction and toe clips with straps were used to prevent the feet from slipping off the pedals. The participants were instructed before the tests that they should pedal as fast as possible and were vigorously encouraged during the test.

The duration of every flywheel revolution in the Wingate anaerobic test was measured with the help of an electronic sensor while the power output of every revolution was computed by specialized software [19]. The results are presented as mean ± *SD* (standard deviation). Data sets were checked for normality using the Shapiro-Wilks normality test and visual inspection. The effect of body mass, fat free mass and age on anaerobic power was examined by the Pearson product moment correlation coefficient (r) and then the coefficient of determination (R^2) was calculated. Differences between the age-groups were assessed using one-way analysis of variance. Correction for multiple comparisons was undertaken using the Bonferroni method. The significance level was set at alpha = 0.05. All statistical analyses were performed using NCSS 2007 computer software (NCSS, USA).

Results

One-way analysis of variance revealed differences between the age-groups regarding P_{peak} in absolute ($F_{9,228} = 26.81$, $p < 0.001$) and relative (to body mass) values ($F_{9,228} = 12.68$, $p < 0.001$), P_{mean} in absolute ($F_{9,224} = 33.82$, $p < 0.001$) and relative values ($F_{9,224} = 10.7$, $p < 0.001$), and minimal power in absolute ($F_{9,224} = 23.8$, $p < 0.001$) and relative values ($F_{9,224} = 4$, $p < 0.001$), while there was no difference in the fatigue index ($F_{9,223} = 4$, *n.s.*). The employment of the Bonferroni method for multiple comparisons revealed particular differences (Tab. 2). Changes in the absolute and rela-

Table 2. Anaerobic power of the study participants

	Age groups									
	U13	U14	U15	U16	U17	U18	U19	U20	U21	Control
P_{peak} (W)	452.36 (114.85) < U15	566.16 (111.41) < U16	626.4 (115.09) < U17	714.27 (122.72) < U20	769.48 (142.35)	774.21 (149.69)	769.66 (94.31)	839.36 (75.35)	852.92 (80.57)	867.86 (89.07)
rP_{peak} ($W \cdot kg^{-1}$)	9.56 (0.68) < U16	9.64 (1.15) < U16	10.31 (0.92) < U18	10.91 (0.83)	10.63 (1.05)	11.23 (0.97)	10.99 (0.81)	11.52 (0.6)	11.21 (0.94)	11.37 (0.66)
P_{mean} (W)	356.7 (82.58) < U14	450.9 (91.99) < U16	490.6 (92.36) < U16	564.5 (90.94) < U20	601.1 (91.14) < Control	614.3 (89.94) < Control	605.6 (58.92)	662 (75.37)	686.4 (55.98)	697.8 (62.07)
rP_{mean} ($W \cdot kg^{-1}$)	7.6 (0.75) < U16	7.73 (0.96) < U16	8.07 (0.88) < U18	8.61 (0.89)	8.56 (1)	8.97 (0.58)	8.66 (0.46)	9.03 (0.78)	9.13 (0.89)	9.16 (0.54)
P_{min} (W)	264.1 (51.01) < U15	338.3 (70.15) < U16	359.6 (87.97) < U17	408.5 (80.55) < U21	427.4 (70.59) < U21	442.9 (57.58) < Control	427.6 (73.65) < Control	468.5 (87.34)	513 (59.74)	521.8 (54.18)
rP_{min} ($W \cdot kg^{-1}$)	5.68 (0.73) < Control	5.83 (0.87) < Control	5.93 (1.07) < Control	6.26 (1.1)	6.11 (0.98)	6.51 (0.68)	6.1 (0.83)	6.39 (1.09)	6.83 (0.95)	6.86 (0.69)
Fatigue index (%)	40.45 (7.69)	39.35 (8.72)	42.26 (10.84)	42.53 (9.1)	42.27 (8.71)	41.76 (7.86)	44.36 (7.91)	44.22 (9.26)	39.55 (7.52)	39.56 (6.12)

Values are presented as mean with standard deviation in brackets. BMI – body mass index; P_{peak} – peak power; P_{mean} – mean power; P_{min} – minimal power; rP_{peak} – relative peak power; rP_{mean} – relative mean power; rP_{min} – relative minimal power. < indicates significant difference between age groups based on Bonferroni post-hoc analysis

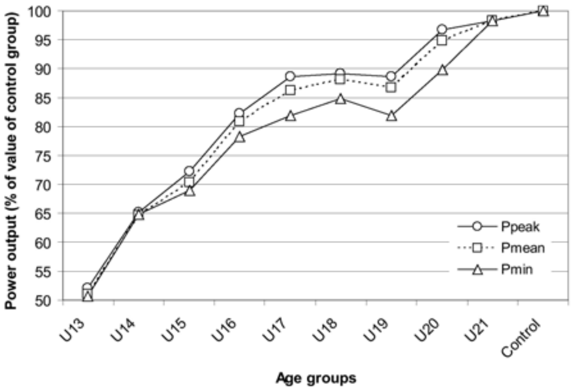

Figure 1. Age-related differences in absolute anaerobic power, presented as a percentage of value of the control group. P_{peak} – peak power; P_{mean} – mean power; P_{min} – minimal power

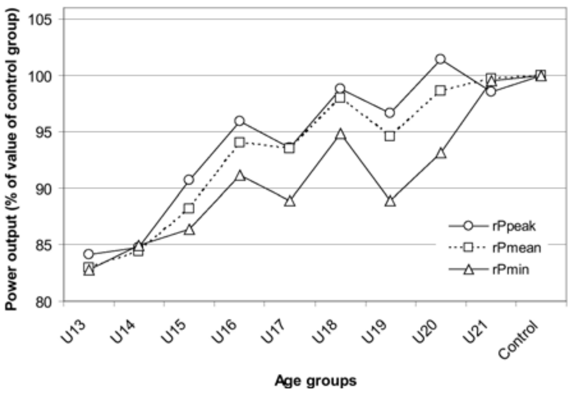

Figure 2. Age-related differences in relative (to body mass) anaerobic power, presented as a percentage of value of the control group. rP_{peak} – relative peak power; rP_{mean} – relative mean power; rP_{min} – relative minimal power

tive (to body mass) anaerobic power indices are illustrated in Figure 1 and Figure 2, respectively. According to Inbar [14], in order to allow for intra- and inter-study comparisons despite differences in the testing procedures, protocols and populations, a common scale is used where values are shown as a percentage when taking the value of control group as 100%.

The Pearson moment correlation coefficient was $r = 0.71$ ($p < 0.001$) between age and P_{peak}, $r = 0.76$ ($p < 0.001$) between age and P_{mean} and $r = 0.70$ ($p < 0.001$) between age and minimal power. When these parameters were expressed in relative (to body mass) values, the respective correlation coefficients were $r = 0.55$ ($p < 0.001$), $r = 0.53$ ($p < 0.001$) and $r = 0.35$ ($p < 0.001$) and when expressed in relative to fat free mass values, the correlation coefficients were $r = 0.51$ ($p < 0.001$), $r = 0.54$ ($p < 0.001$) and $r = 0.35$ ($p < 0.001$), accordingly. P_{peak} was highly correlated to body mass ($r = 0.93$, $p < 0.001$, $R^2 = 0.86$) and fat free mass ($r = 0.94$, $p < 0.001$, $R^2 = 0.88$), as well as P_{mean} ($r = 0.89$, $p < 0.001$, $R^2 = 0.80$; $r = 0.93$, $p < 0.001$, $R^2 = 0.86$, respectively) and minimal power ($r = 0.76$, $p < 0.001$, $R^2 = 0.57$; $r = 0.81$, $p < 0.001$, $R^2 = 0.65$, respectively).

Discussion

Although it is clearly recognized that anaerobic power is linked to performance in soccer, little is known about the short-term power output of those who practice this sport. This is the first study to examine the relationship between age and the main indicies of the WAnT (P_{peak}, P_{mean} and FI) in a large sample of young male soccer players. First, we examined the level of the participants' anaerobic power in light of the previous studies. Overall, the participants exhibited high levels of anaerobic power. The anaerobic power of our study sample was comparable to that of the US Olympic team [3] and superior to that of the general population [20, 21]. Compared with 12.2 y boys [20], the U13 age group (12.37 y) had higher P_{peak} (417.13 W vs. 321 W), rP_{peak} (8.88 W · kg^{-1} vs. 7.89 W · kg^{-1}), P_{mean} (318.7 W vs. 269 W) and rP_{mean} (6.84 W · kg^{-1} vs. 6.61 W · kg^{-1}). Compared with normative data of the general population [21], the adult players received a score of "excellent" on a 7-degree scale (from "very poor" to "excellent") in P_{peak} and P_{mean}, and they were classified higher than the 95th percentile. These findings confirmed anaerobic power as an important sport-related physical fitness parameter in soccer.

Second, we demonstrated that P_{peak} and P_{mean} significantly differed between the age groups of the young players, i.e., the older the group, the higher the short-term power output, whereas there was no difference with regard to FI. Correspondingly, there was a direct relationship between age and P_{peak} and P_{mean} either in absolute or relative to both body mass or fat free mass values. Our findings were scrutinized in light of the previous data on the general population [13] and on soccer players [3, 16]. In these studies, P_{peak} was 9.3 ± 0.2 W · kg^{-1} in U14, 10 ± 0.3 W · kg^{-1} in the U15 and 10.5 W · kg^{-1} in U16 group, P_{mean} 8 ± 0.2 W · kg^{-1}, 8.1 ± 0.2 W · kg^{-1} and 8.7 ± 0.2 W · kg^{-1}, and FI 27.1 ± 1.9%, 36.8 ± 1.9% and 35 ± 1.9%, respectively [3], while the corresponding values in older adults were 10.6 ± 0.9 W · kg^{-1}, 8.7 ± 0.4 W · kg^{-1} and 36.3 ± 7.4% [16]. In research on the general population, mean power was increased from 6.3 ± 1.1 W · kg^{-1} (11–12 y) to 6.7 ± 1.2 W · kg^{-1} (13 y) and 7.6 ± 1 W · kg^{-1} (14–15 y) [13].

The increase of anaerobic power across adolescence in soccer players (from U13 to U19, +70% in P_{peak}) was lower than what was reported in previous studies [2, 12, 20]. In particular, maximal power, estimated by a combination of 40 m sprint time and body mass, increased by 152% in soccer players from 11 y to 18 y (1046 ± 122 W and 2641 ± 384 W), and, when estimated by a combination of countermovement vertical jump displacement and body mass, increased by 127% (448 ± 51 W and 1017 ± 92 W; [2]), while in the general population an increase of 100% (461.5 ± 80.4 W and 923.8 ± 179.8 W) was reported [12]. P_{peak}, an index of WAnT, increased by 120% from 12.2 y to 17 y (321 ± 83 W and 707 ± 114 W; [20]). This discrepancy should be attributed to differences in the assessment methods and in the training levels, as it is expected that in a more homogeneous sample a smaller variability of the physiological parameters can be identified.

Third, the association between short-term power output and body mass and body composition was investigated. Body mass and fat free mass were as high as 86% and 88%, respectively, to the variance in P_{peak}. The respective values for P_{mean} were 80% and 86%, while for P_{min} they were 57% and 65%.These findings came to terms with previous observations on the anaerobic power of the general male population across adolescence [12, 14], in which a large proportion of the variance in anaerobic power was accounted for by body mass. Moreover, pubescent male soccer players (e.g. U13) exhibited about 50% of their adult counterparts absolute anaerobic power, while the corresponding percentage on relative to body mass values was close to 85%, highlighting the role of body mass and fat free mass as the main determinants of anaerobic power. This influence of body mass is also indicated by the much slower rate of increase in relative rather than absolute anaerobic power (Fig. 1 and Fig. 2).

Consequently, there still remains a small proportion of variance that needs to be explained by other factors. Bar-Or and Rowland [22] pointed out possible reasons for low anaerobic performance in children, such as smaller muscle mass per body mass, lower glycolytic capability and deficient neuromuscular coordination. These conditions seem to be attenuated during adolescence and eradicated in adulthood. In addition to these conditions, three biomechanical factors were also identified as determinants of anaerobic power [14]: the increase of the length of lower limbs' levers, the increase of muscular groups' power, and technique.

Physical fitness has a strong interrelationship with physical activity (PA), i.e. higher PA levels result in higher fitness scores, while people with higher fitness scores achieve higher PA levels. A main limitation of any study based on current fitness scores, in the context of talent identification, is whether the attribution of a physical ability can be made to talent or previous training and remains questionable. In our study, the participants were interviewed about their current training load (weekly time basis) and previous experience (years engaged in soccer). However, the possibility still remains that the physiological characteristics of better players are due to a systematic approach to training prior to their induction to the team [1] or due to current non-sport physical activity levels.

This study was carried out on Greek soccer players. Consequently, its results could also be generalized to similar populations of other countries, on the assumption that these countries are found on a similar or lower level than Greece (10th FIFA world ranking as of February 2011; [23]). It is presumed that at a higher international level, considering the contribution of physical fitness on soccer performance, players have better anaerobic power among the other parameters of physical fitness and, therefore, differences between age groups may be attenuated or even be considered null.

These findings could be integrated in either a short--term or long-term training plan for sport-related fitness improvement or talent identification, respectively. However, identifying talent for soccer at an early age is far from being a mechanistic process [24], i.e., it is more complex in team sports than in individual sports where there are discrete objective measures of performance. Since most of the contemporary research in soccer has been carried out on adults, data about the evolution of anaerobic power from childhood to adulthood could also be employed by a coach or fitness trainer towards determining optimal training load. For instance, the findings in the present study can be employed as normative data and the differences of both absolute and relative to body mass values of anaerobic power should be taken into account in the training process.

Conclusion

Considering the importance of short-term high-intensity activities in soccer performance and the lack of information about the anaerobic profile of adolescent players, the short-term power output across adolescence, as assessed by WAnT, was investigated in this paper. The anaerobic profile of the participants was found to be superior with regard to the general population. P_{peak} and P_{mean} were significantly less in those soccer players at the lower spectrum of adolescence than for their older counterparts, even after adjustment for body mass or fat free mass, and there was a direct relationship between these WAnT indices and age. Thus, our findings confirmed the pattern of anaerobic power development across adolescence that was already investigated in the general population. However, what is novel is the quantification of such a pattern in soccer players, where such findings could be implemented in the training process for sport-related fitness improvement or talent identification.

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COMPARISON OF THE 3´BIKE TEST WITH THE ASTRAND BIKE TEST BY VO_2MAX

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ABSTRACT
Purpose. The goal of this study was to compare two sub-maximal exercise tests used in predicting VO_2max.abs, the 3´Bike Test, which has not previously been used as a functional test, and the Astrand Submaximal Bike Test. **Methods.** 1492 athletes aged 16–35 years were tested. After anthropometrical measurements, each athlete performed the new 3´Bike Test, and after resting for one hour, they performed the Astrand Bike Test. **Results.** Based on the data collected, when looking for correlations between the two tests' variables that indicate VO_2max.abs, finds that the 5th minute of Astrand Bike Test realized its best correlation with the 3rd minute of the 3´Bike Test. This significant partial correlation between the 5th minute of the Astrand Bike Test and 3rd minute of the 3´Bike Test points to some similarities between these two tests. Linear regression of the data indicates that the system of predictive variables of the 3´Bike Test explains for 36.4% of total variability of the dependent variable (VO_2max.abs) with a lower standard error of estimate of 0.247. Whereas the system of predictive variables of the Astrand Bike Test explains for 31.9% of total variability, with a standard error of estimate at 0.256. The third minute of the 3´Bike Test, with a beta-coefficient of –0.54, indicates better predictive influence of VO_2max.abs when compared to other test variables. **Conclusions.** According to the above-mentioned results, it can be concluded that the new applied functional test, the 3´Bike Test, better predicts VO_2max.score when compared with the Astrand-Bike Test.

Key words: VO_2max.abs, regression analyses, Beta-coefficient, aerobic work

Introduction

Aerobic endurance refers to the ability to sustain work for prolonged periods of time. During aerobic work, oxygen is obtained from air and transferred from the lungs to the bloodstream where it reaches the muscles via the circulatory system. Knowledge of an individual's aerobic capacity is important for athletes, coaches, exercise scientists, those in military service, and for others who exercise. An individual's aerobic ability may be evaluated by basing it on a number of indicators, such as VO_2max.score, anaerobic threshold and heart rate (HR). In practice, the most often used indicator for this purpose is VO_2max.score [1], which can be measured by different maximal and submaximal tests [2].

VO_2max.score describes the maximum amount of oxygen that the body can uptake during highly intensive aerobic exercise [3, 4]. VO_2max can be expressed as an absolute or relative. VO_2max.absolute specifies the amount of oxygen that the body can uptake in a minute and is expressed in liters per minute (L/min). VO_2max.relative is expressed in milliliters per kilogram or body weight per minute (ml/kg/min). A high value of VO_2max is a good indicator of aerobic endurance, and indicates how difficult an individual may find aerobic activities such as walking, running, cycling or swimming [5].

A number of maximal or submaximal exercise tests are often used to estimate an individual's VO_2max.score and thus their fitness level [3, 4, 6, 7]. The maximal tests that evaluate VO_2max, when compared to submaximal tests, require far more sophisticated equipment, highly skilled technicians, financing, as well as requiring the subject to be pushed to their limit (until they reach exhaustion). However, for a functional test to be widely applicable, it should be reliable, valid and should be economical in its duration as well as cost. More simpler submaximal tests, such as the Astrand Submaximal Bike Test [2, 8, 9], were found to highly correlate (85–90%) with these advanced tests in evaluating VO_2max.

According to Foss and Keteyian, the Astrand Submaximal Bike Test registers only ± 15% standard deviation from directly measured VO_2max [10]. This test, based on the early work of Astrand and Rhyming, and in addition Sjostrand, still remains to be the most frequently used submaximal test in evaluating aerobic capacity [11]. It is simple to administer as it involves only a single stage, thus it is a uniform and continual test with the same load and same pedal revolution frequency. The workload is set during the first minute and maintained throughout the duration of the test. The goal is to achieve a steady heart rate over a 5–6

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minute period. The average heart rate at a particular level is then correlated to an estimate of the subject's oxygen capacity [3, 4]. VO_2max may then be determined by using a nomogram that utilizes the workload value and steady-state heart rate [12, 13] or by using the Döbeln formula [14, 15]. As such, the goal of this study was to assess, as well as apply, a new functional 3 minute test (the 3´Bike Test) that has not been previously used and compare it to the Astrand Bike Test. The Astrand Bike Test, as a continual test with constant load and a constant speed of pedaling, differs from the 3´Bike Test, as it is a continuous test with a progressive load with a progressive frequency of pedaling. This new test was expected to be as reliable and valid as the currently used test, as well as to be more economical in terms of its duration. To accomplish this, a comparison of the interrelations between these two submaximal exercise tests (the 3´Bike Test and Astrand Bike Test) was performed through analysis of VO_2max.abs.

Material and methods

The research in this study was part of the "Testing and Applying of a New Functional Test" project, assessed at the Center for Sport Medicine and Recreation in Prishtina, Kosovo during 2008–2010. The procedures were in accordance with the ethical standards of the Ethics Committee of University Clinical Center in Pristina. The functional tests were performed on 1492 athletes aged 16–35 years from Kosovo. All of the athletes had been active football players for more than two years.

The necessary equipment to perform the tests was an ergo-cycle (fitness bike), a chronometer and a stethoscope or heart rate monitor. The testing procedure was as follows: the athletes were first submitted to an anamnesis to evaluate the presence of any health conditions that could restrict their participation in both of the submaximal tests. After measurement of body weight, the ergocycle was adjusted to each subject and then each athlete performed the new 3´Bike Test, and after a recuperation period of approximately one hour (once they had regained pre-testing heart rate values) they performed the Astrand Submaximal Bike Test.

The Astrand Submaximal Bike Test was performed according to the general guidelines of this test. For the Astrand Test, the workloads of the subjects were dependent on their age and fitness capabilities (maximal load = 300 W; minimal load = 50 W; average load = 169 W). The procedure of the 3´Bike Test was the same for all participants (independent of their age or fitness capabilities) and was as follows: for the first minute, a work load of 100 Watt and a pedal frequency of 60 revolutions per minute (60 rev/minute); for the second minute: a work load of 100 Watt and a pedal frequency of 100 rev/minute; for the third minute: a work load of 150 Watts and a pedal frequency of 100 rev/minute.

For the tests, the following variables were measured:

- BW – Body Weight (kg);
- HR0' – Heart rate during rest;
- HR 100/60 – Heart rate in the 1^{st} minute of the 3´Bike Test;
- HR 100/100 – Heart rate in the 2^{nd} minute of the 3´Bike Test;
- HR 150/100 – Heart rate in the 3^{rd} minute of the 3´Bike Test;
- HR1' – Hart rate in the 1^{st} minute during the Astrand Sub maximal Bike Test;
- HR2' – Hart rate in the 2^{nd} minute during the Astrand Sub maximal Bike Test;
- HR3' – Hart rate in the 3^{rd} minute during the Astrand Sub maximal Bike Test;
- HR4' – Hart rate in the 4^{th} minute during the Astrand Sub maximal Bike Test;
- HR5' – Hart rate in the 5^{th} minute during the Astrand Sub maximal Bike Test;
- VO_2max.abs – Absolute maximal oxygen uptake (L/min)

Absolute maximal oxygen uptake (VO_2max.abs.) was calculated by using the Döbeln formula:

$$VO_2\text{max abs} = 1.29 \sqrt{\frac{L}{fh - 60}}\, e^{-0.00884T}$$

L – Level of load (kpm/min)
fh – Heart rate in the 5^{th} minute during the submaximal test
e – Coefficient 2.72
T – Years of age

The obtained data were analyzed using basic statistical parameters, multiple and partial correlation, as well as regression analysis. All of the statistical procedures were conducted with statistical software (SPSS 15, IBM, USA).

Results

The results, provided as descriptive statistics (minimum, maximum, mean and standard deviation values) of the measured variables, are shown in Table 1. The percentage of maximal heart frequency that the athletes reached at the end of each test shows that at the end of the 3´Bike Test the athletes reached 74% of their predicted Maximum Heart Rate (MHR), while at the end of the Astrand Submaximal Bike Test they reached 79% of their age-predicted MHR. The calculations used were:

- % MHR 3´Bike Test = HR3'/(220–Age) = 148/(220–21) = 74%
- % MHR Astrand Bike Test = HR5'/(220–Age) = 157/(220–21) = 79%

Table 1. Descriptive parameters of the measured variables

	N	Mini	Maxi	Mean	Std. dev.
Age	1492	16.00	35.00	21.2775	4.16358
BW	1492	47.40	108.00	72.5521	8.39472
HR 0’	1492	46.00	98.00	69.3157	9.85340
HR 100/60	1492	80.00	160.00	117.0469	12.93353
HR 100/100	1492	88.00	184.00	135.5174	14.57736
HR 150/100	1492	98.00	196.00	147.8432	14.80450
HR 1’	1492	100.00	160.00	136.1548	9.82507
HR 2’	1492	108.00	164.00	143.6347	10.22903
HR 3’	1492	112.00	168.00	148.9477	10.63642
HR 4’	1492	118.00	170.00	153.1320	10.92818
HR 5’	1492	118.00	174.00	156.6066	11.40376
VO_2max.abs	1492	2.60	5.20	3.5385	0.31079
Workload-Ast. (W)	1492	100.00	300.00	176.7091	29.10631

N – the number of subjects
Mini – minimal value
Maxi – maximal value
Mean – mean (average value)
Std. dev. – standard deviation

Table 2 shows the coefficients of correlation between the measured variables. Although all of the variables indicate significant intercorrelations, it can be easily noticed that their distribution appears to be split into two groups. In the first group, three variables of the 3´Bike Test and VO_2max.abs are concentrated, whereas in the second group all of the variables of the Astrand Bike Test are concentrated. All of these correlations were expected, except for VO_2max.abs, which even if calculated from a value of HR from the 5th minute of Astrand Bike Test would have a higher correlation in the same group with all of the variables of the 3´Bike Test.

Table 3 shows the coefficients of partial correlation between the heart rate in the 3rd minute of the 3´Bike Test and the heart rate in the 5th minute of the Astrand Bike Test. These two measured variables have significant partial intercorrelation, which encouraged this team to continue with other statistical procedures.

Regression models, whose predictive system is based on physiological variables, achieved maximum precision in the prediction of the dependent variables and was the reason for selecting tests that contained mainly physiological variables [1]. Because the variables of age and HR5’ of the Astrand Bike Test are integrated as a dependent variable (VO_2max.abs), both were eliminated from the system of predictive variables. According to the results found in Table 4, we can conclude that the system of predictive variables (the nine measured variables) can significantly explain 44.4% of the total variability of VO_2max.abs as a dependent variable. Whereas, as presented in Table 5, the variable that has more predictive influence on the dependent variable can be extracted. The higher values of beta coefficients, shown in Table 5, indicate that the variable HR 150/100, with a beta coefficient of –0.43, has higher predictive influence on VO_2max.abs when compared to the other variables. It is interesting that this variable has more predictive influence than the variables of the Astrand Bike Test, from which it had been estimated as the dependent variable.

To explore the independent influence of the variables of each test on the dependent variable (VO_2max.abs), a regression analysis was separately conducted for each test.

Table 3. Partial correlation coefficients, controlled for VO_2max.abs

	HR 150/100	HR 5’
HR 150/100	1.00	0.093
HR 5’	0.093	1.00

2-tailed significance at $p = 0.000$

Table 2. Correlations between measured variables

	HR100/60	HR100/100	HR150/100	HR1’	HR2’	HR3’	HR4’	HR5’	VO_2max
HR 100/60	1								
HR 100/100	***0.868**	1							
HR 150/100	***0.819**	***0.924**	1						
HR 1’	*0.461	*0.427	*0.446	1					
HR 2’	*0.427	*0.411	*0.434	***0.898**	1				
HR 3’	*0.392	*0.378	*0.413	***0.835**	***0.935**	1			
HR 4’	*0.350	*0.335	*0.374	***0.786**	***0.889**	***0.949**	1		
HR 5’	*0.331	*0.317	*0.358	***0.756**	***0.854**	***0.918**	***0.966**	1	
VO_2max.abs	***–0.500**	***–0.540**	***–0.589**	*–0.485	*–0.480	*–0.472	*–0.481	*–0.497	1

* Correlation is significant at the 0.01 level (2-tailed). Bold signifies the distribution into two groups.

Table 4. Regression analyses of all the measured variables

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Sig.
1	0.669	0.447	0.444	0.232	0.000

Dependent variable: VO_2max.abs
Predictors: (Constant), BW, HR 100/100, HR 1', HR 100/60, HR 150/100, HR 3', HR 2', HR 4'
R – correlation, R^2 – multiple correlation
Adjusted R^2 – adjusted multiple correlation based on the number of subjects, Sig – significance (probability)

Table 5. Beta Coefficient for each measured variable

	Beta Coefficients	*t*	Sig.
BW	0.126	5.982	0.000
HR 100/60	0.008	0.191	0.849
HR 100/100	0.003	0.053	0.958
HR 150/100	–0.430	–8.223	0.000
HR 1'	–0.153	–3.411	0.001
HR 2'	0.029	0.418	0.676
HR 3'	0.223	2.809	0.005
HR 4'	–0.416	–6.746	0.000

Dependent variable: VO_2max.abs
t – *t* value, Sig – significance (probability)

Table 6 shows that the system of variables of the 3´Bike Test explains for 36.4% of total variability of the dependent variable (VO_2max.abs). Similarly, as shown in Table 5 and Table 7, finds that variable HR 150/100, with a beta coefficient value of –0.542, has a higher predictive influence on VO_2max.abs as the dependent variable.

Table 8 indicates that the predictive system of the Astrand Bike Tests' variables poorly explains the total variability (31.9%) of the dependent variable (VO_2max.abs) when compared with the predictive system of the 3´Bike Tests variables.

According to Table 9, it can be concluded that each variable of the Astrand Bike Test has lower predictive influence on the dependent variable (VO_2max.abs), compared with third variable of 3´Bike Test (HR150/100) (Tab. 7). It seems that the response of the cardiovascular system of the tested athletes is more utilitarian during functional increment tests (as in the 3'Bike Test) than during functional constant tests.

Table 6. Regression analyses of the 3´Bike Test

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Sig.
1	0.605	0.366	0.364	0.248	0.000

Dependent variable: VO_2max.abs
Predictors: (Constant), HR 150/100, BW, HR 100/60, HR 100/100

Table 7. Beta coefficients of the 3´Bike Test's variables

	Beta Coefficients	*t*	Sig.
BW	0.145	6.478	0.000
HR 100/60	–0.073	–1.753	0.080
HR 100/100	0.075	1.201	0.230
HR 150/100	–0.542	–9.840	0.000

Dependent variable: VO_2max.abs

Table 8. Regression analyses of the Astrand Bike Test

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Sig.
1	0.567	0.321	0.319	0.256	0.000

Dependent variable: VO_2max.abs
Predictors: HR 4, BW, HR 1, HR 2, HR 3

Table 9. Beta Coefficients of the Astrand Bike Test variables

	Beta Coefficients	*t*	Sig.
BW	0.251	11.399	0.000
HR 1'	–0.248	–5.081	0.000
HR 2'	–0.013	–0.172	0.864
HR 3'	0.130	1.484	0.138
HR 4'	–0.349	–5.128	0.000

Dependent variable: VO_2max.abs

Discussion

The aim of this research was to make a comparison between two different submaximal bike tests in order to assess the reliability and validity of a new applied functional test which has undisputed economic benefits due to its duration. The results can be discussed in view of the performed statistical analysis. The findings, based on the descriptive statistics, indicate that at the end of the 3´Bike Test the athletes performed at an intensity of 74% of their age-predicted maximum heart rate, whereas at the end of the Astrand Submaximal Bike Test they reached 79% of age-predicted maximum heart rate.

The correlations of the measured variables found certain distribution of their coefficients in two groups. Surprisingly, the variable VO_2max.abs, even when calculated from the 5th minute of the Astrand Submaximal Bike Test, realized its best correlation with the variables of 3´Bike Test, especially with the 3rd variable (HR 150/100 = 0.589). The significant partial correlation between the 5th variable of Astrand Submaximal Bike Test and the variable HR 150/100 of the 3´Bike Test points to some similarity between these two physiological variables in the two different tests.

Comparing the data of regression analyses of each test, we noticed that the system of predictive variables of the 3´Bike Test better explain total variability (36.4%) of the dependent variable (VO_2max.abs), with a lower standard error of the estimate (0.248), whereas the system of predictive variables of the Astrand Submaximal Bike Test are not better indicators of the total variability (31.9%), with a higher standard error of the estimate (0.256). Again, surprisingly, the third variable of 3´Bike Test (HR 150/100) has a higher beta coefficient value (–0.54). It has been shown that this variable indicates the best predictive influence on VO_2max.abs as a dependent variable [9]. These results clarify that the VO_2max.abs of athletes may be better assessed through submaximal continual tests with a progressive work load and a progressive frequency of pedaling when compared to submaximal continual tests with a constant work load and a constant frequency of pedaling.

Conclusion

Both tests did not provoke similar maximal heart rates, with the 3´Bike Test showing a lower percentage of maximal heart rate compared to the Astrand Submaximal Bike Test. One could assume that to achieve a similar percentage (%) of maximum heart rate of both tests used in this research, the workload in the 3´Bike Test would also need to be adjusted depending on the subject's age and fitness capabilities.

The regression models applied in this research suggest that the 3´Bike Test has higher efficiency in predicting VO_2max.abs as a dependent variable when compared to the Astrand Submaximal Bike Test. Another feature in favor of this test is the lower economic cost and increased time efficiency (the duration of the 3´Bike Test is 3 minutes, while the duration of Astrand Bike Test is 5–6 minutes). Further tests can be carried out with subjects placed into different groups (based on similar age and psycho-physical characteristics) and additional statistical analysis performed in order to calculate the best formula of the 3´Bike Test to estimate VO_2max.abs.

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THE RELATIONSHIP AMONG THE SOMATIC CHARACTERISTICS, AGE AND COVERED DISTANCE OF FOOTBALL PLAYERS

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ABSTRACT
Purpose. The aim of this article was to define the somatic characteristics, BMI index, age and total distance covered of football players who participated in the 2008 European Football Championships. The article also pointed to any significant interrelationships. **Methods.** On the basis of a game analysis system, the Castrol Performance Index, the 248 football players who participated in all 32 games of the Championships were subject to analysis based on the distance covered during the games, with the results statistically analyzed and compared with the players' somatic characteristics. In addition, the Kruskal-Wallis test was used as a non-parametric counterpart of one-way analysis of variance. **Results.** The highest values of the somatic characteristics such as height, body mass, age and the BMI index were found in goalkeepers. The longest distances covered during the games were attained by midfielders and side midfielders, whereas the shortest distances covered were by goalkeepers and central defenders. Larger values of height and body mass corresponded to smaller covered distances by players during the games. **Conclusions.** The indicated dependences, which were found among the players' age, height, body mass and covered distance during the games allows one to define the usefulness of a player in a particular team formation. The covered distance, particularly in correlation with the mentioned morphological indicators, which to a great extent are genetically conditioned, could be used as criterion towards specifying in the most accurate way which formation a particular player should play in, based on his genetic predisposition.

Key words: somatic characteristics, covered distance, football, soccer

Introduction

There is increasing interest in the analysis of football matches based on the empirical data that can be observed during gameplay. Any relevant aspects that can have influence on players' performance are sought out, as this data can provide a precise estimate of players' capabilities and, therefore, be a contributing factor to sporting success. Observation is the most useful method in noting the specific actions that occur in a game of football, which, by basing it on the activity of the players, provides pertinent information about the contribution of each player within the collective effort of a team [1, 2]. This method of observation is used to describe the structure and functional characteristics of the players who play in the world's leading football teams [3–7]. Here, kinetic studies are a useful method in analyzing the involvement of a player during a match [8]. The main benefits of this non-invasive form of data collection is the possibility of determining the distance covered by individual football players during gameplay as well as the acquisition of data related to the duration and frequency of participation of various types of player behaviors during a game. These results can provide knowledge of players' energy expenditure as well as the work performed and its intensity during gameplay [9].

The nature of physical exercise that is present in the game of football is a complex process due to its dynamic, random and intermittent nature [10]. This fact necessitates the involvement of many bodily processes in a football player, which of special importance are the body's aerobic processes, which should have very high values in football players [3, 5, 11]. High-level football players perform from 150 to 250 game actions and almost 1100 changes in the direction of travel on the field. There are considerable individual variations in the physical capabilities of players during gameplay, and, as such, they are conditioned by the physical abilities and the role played by each of the players on a team [10, 12]. The game of football forces these high-level players to perform extremely arduous work in moving non-stop around the football field for a total 90 minutes. On average, the world's elite players cover a distance of 10 000 to 13 500 metres during each game [1, 2, 12]. The variation in the distance covered depends on the formation and position played. The greatest distances covered in a game are by midfielders, on average about 11 500 m, while for those playing defense and offense, about 10 500 m [7, 13].

Among many other factors, some that are considered the most important in assessing the performance

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of football players include the player's experience, body height and mass, ambition, endurance and their balance between aerobic and anaerobic processes [9]. The position that a player plays on the field also affects their total energy expenditure in a game. It is suggested that, among the players that play in certain formations, there are significant differences in their height and weight as well as body mass index values. Researchers have found that the role of the player in a formation during gameplay has a huge impact on players' energy expenditure [8, 10, 14].

Therefore, in this paper, the authors calculated the somatic characteristics and age of the high-level players that participated in the 2008 European Football Championship finals, broken down among the specific formations played, and attempted to determine the relationship between these characteristics and the distance covered by the players during a match. It was hypothetically assumed that the distance covered during a match is different, depending on the formation as well as the somatic characteristics and age of the players.

Material and methods

For this study, data was collected from a game analysis system, the Castrol Performance Index. This Index is an advanced and complex data collection system that had been previously used in military aviation to track enemy targets. Two camera systems, each composed of four cameras, monitor and record every second of the game on the entire field. The players are given individual tracking codes by which the cameras are able to recognize and follow them while recording.

Previously, game analysis systems focused on developing post-game analysis, using human visual observation in noting passes and goal shots. The Castrol Performance Index is a tool that can accomplish the same thing, but in real time, collecting data from cameras that record at 25 frames per second. This system is able to log the following parameters: a) the position of all the players at any given moment during the game, b) the speed of the players and ball, c) the distances between the players, d) the distance travelled on the field, e) the actions performed between players, f) and referee statistics [15].

Besides the standard division of players into the four existing football positions: goalkeepers, defenders, midfielders, and strikers, this study further subdivided the positions of defenders and midfielders into those who play central and wide positions. This division was based on the increasingly varied tasks of players who play in those formations. Most teams make use of tactics where one striker is supported by his side midfielders, as wings during an offensive phase, or two strikers who play close together, therefore, the striker formation needed no additional division of its players' positions.

This study also took into consideration the distance covered by goalkeepers, which in many studies is omitted due to the specificity of that position, although the goalkeeper does take on the role of acting as the last defender. The shorter distance that is covered by these players influence, to some extent, the values calculated for the mean distance covered.

The data used in the study was the total distance travelled by the 248 players in all 32 games of the men's European Football Championships in 2008 as well as their somatic characteristics. The measurement of total distance covered *includes the total distance measured during an entire game as well as broken down into each of its halves*. When calculating the mass, height and age of the players, data was collected from the Championship's official website [16], with the results given in kilograms (kg), metres (m) and years (y), respectively.

Using statistical software, calculations were made on all of the obtained data. Common measurements, such as the arithmetic mean and the variability of standard deviation, were used. Since the analyzed variables did not meet the assumptions necessary for parametric tests due to a lack of normal distribution and equal variance, as well as finding that the variables are not quantifiable, the Kruskal-Wallis test was used, as it is a non-parametric equivalent of one-way analysis of variance. Any difference was defined as statistically significant at $p < 0.05$.

Results

Analysis of the players' somatic characteristics found that the mean body height was 182.5 ± 6.6 cm while body mass was found to be 76.5 ± 6.5 kg. The weight-height coefficient of BMI was calculated to be 22.9 ± 1.0, and the mean age was 27.9 ± 3.9 y (Tab. 1). Significant statistical differences at $p < 0.05$ were found in the subjects' morphological characteristics and age as well as the covered distance in the specific formations, as evidenced by the high values in the Kruskal-Wallis test (Tab. 2).

The highest body height in relation to the players of the other formations was those of goalkeepers, at 189.7 ± 4.8 cm. Similar values of this parameter were found in central defenders, at 186.7 ± 5.0 cm, however this value was not significantly different, when compared to the rest of the formations. Among the analyzed formations, those with the lowest values of height were those of side midfielders, at 179.0 ± 5.3 cm, and central midfielders, at 179.6 ± 5.9 cm. These values were significantly lower than the height values of strikers, at 182.8 ± 6.9 cm, and side defenders, at 181 ± 5.2 cm (Tab. 2).

In addition, the body mass of goalkeepers, at 84.4 ± 5.1 kg, was significantly higher than in the other formations. The lowest body mass was found among

Table 1. The somatic characteristics of the players in each of the formations in the men's 2008 European Football Championships

Formation	Players' somatic characteristics and age			
	Body height (cm)	Body mass (kg)	BMI	Age (years)
B (1) ($\bar{x}$ ± SD)	189.7 ± 4.8 ^{3,4,5,6*}	84.4 ± 5.1 ^{2,3,4,5,6*}	23.4 ± 0.9 ^{3,5*}	30.5 ± 4.9 ^{3,5,6*}
OŚ (2) ($\bar{x}$ ± SD)	186.7 ± 5.0 ^{3,4,5,6*}	79.8 ± 5.3 ^{1,3,4,5,6*}	22.8 ± 1.0	28.6 ± 3.5 ^{3,5*}
OB (3) ($\bar{x}$ ± SD)	181.5 ± 5.2 ^{1,2,5*}	74.7 ± 5.8 ^{1,2,5*}	22.6 ± 0.9 ^{1,4*}	27.2 ± 3.2 ^{1,2*}
PŚ (4) ($\bar{x}$ ± SD)	179.6 ± 5.9 ^{1,2,6*}	74.7 ± 5.7 ^{1,2,5*}	23.1 ± 1.0 ^{3,5*}	28.3 ± 3.8 ^{5*}
PB (5) ($\bar{x}$ ± SD)	179.0 ± 5.3 ^{1,2,3,6*}	72.6 ± 4.8 ^{1,2,3,4,6*}	22.6 ± 0.9 ^{1,4*}	26.1 ± 3.6 ^{1,2,4*}
N (6) ($\bar{x}$ ± SD)	182.8 ± 6.9 ^{1,2,4,5*}	76.5 ± 6.5 ^{1,2,5*}	22.8 ± 0.9	27.5 ± 3.5 ^{1*}
Total ($\bar{x}$ ± SD)	182.5 ± 6.6	76.5 ± 6.5	22.9 ± 1.0	27.9 ± 3.9

B (1) – goalkeeper; OŚ (2) – central defender; OB (3) – side defender; PŚ (4) – central midfielder; PB (5) – side midfielder; N (6) – striker
* the numbers in superscript are the variables for which the differences between the means is statically significant at $p < 0.05$

Table 2. Difference in players' body height among the formations (Kruskal-Wallis test)

Dependent: body height in the formations	The value of the Kruskal-Wallis test H = 192,773 p = 0.001*					
	B (1) R: 552.1	OŚ (2) R: 469.1	OB (3) R: 313.4	PŚ (4) R: 247.5	PB (5) R: 238.2	N (6) R: 349.8
B (1)	X	0.101	0.001*	0.001*	0.001*	0.001*
OŚ (2)	0.101	X	0.001*	0.001*	0.001*	0.001*
OB (3)	0.001*	0.001*	X	0.088	0.040*	1.000
PŚ (4)	0.001*	0.001*	0.088	X	1.000	0.001*
PB (5)	0.001*	0.001*	0.040*	1.000	X	0.001*
N (6)	0.001*	0.001*	1.000	0.001*	0.001*	X
Suma of ranks	34236.5	58175.5	39498.5	36136.0	28830.0	36029.5

B (1) – goalkeeper; OŚ (2) – central defender; OB (3) – side defender; PŚ (4) – central midfielder; PB (5) – side midfielder; N (6) – striker; * level of significance $p < 0.05$

Table 3. Difference in players' body mass among the formations (Kruskal-Wallis test)

Dependent: body mass in the formations	The value of the Kruskal-Wallis test H = 183,555 p = 0.001*					
	B (1) R: 567.3	OŚ (2) R: 453.1	OB (3) R: 294.3	PŚ (4) R: 293.1	PB (5) R: 220.3	N (6) R: 339.6
B (1)	X	0.003*	0.001*	0.001*	0.001*	0.001*
OŚ (2)	0.003*	X	0.001*	0.001*	0.001*	0.001*
OB (3)	0.001*	0.001*	X	1.000	0.047*	1.000
PŚ (4)	0.001*	0.001*	1.000	X	0.039*	1.000
PB (5)	0.001*	0.001*	0.047*	0.039*	X	0.001*
N (6)	0.001*	0.001*	1.000	1.000	0.001*	X
Sum of ranks	35173.0	56186.0	37088.0	42805.0	26666.5	34985.5

B (1) – goalkeeper; OŚ (2) – central defender; OB (3) – side defender; PŚ (4) – central midfielder; PB (5) – side midfielder; N (6) – striker; * level of significance $p < 0.05$

players playing as side midfielders, at 72.6 ± 4.8 kg (a value significantly lower than in the other analyzed groups of players), and central midfielders, at 74.7 ± 5.7 kg, as well as side defenders, at 74.7 ± 5.8 kg. Similar to what was found with height, central defenders had the mass closest to those of goalkeepers, while comparable values were found for side defenders and central midfielders with strikers (Tab. 3).

Among the players who were goalkeepers, the weight-height coefficient BMI was found to be 23.4 ± 0.9, which also was found to be the highest, and very close to the values found in central midfielders, at 23.1

± 1.0, central defenders, at 22.8 ± 1.0, and strikers, at 22.8 ± 0.9. The lowest BMI values were those of side midfielders, at 22.6 ± 0.9, and side defenders, at 22.6 ± 0.9 (Tab. 4).

Age was also found to be significant in the players of each formation. In this case the highest values were again found in goalkeepers, at 30.5 ± 4.9 y. This value was significantly higher when compared to players who played as side midfielders, at 26.1 ± 2.6 y (this formation was composed of the youngest players), side defenders, at 27.2 ± 3.2 y, and strikers, at 27.5 ± 3.5 y (Tab. 5).

Analysis of the distance covered in the analyzed Championships found that, on average, each player

Table 4. Difference in players' BMI index among the formations (Kruskal-Wallis test)

Dependent: BMI index in the formations	The value of the Kruskal-Wallis test $H = 38.201$ $p = 0.001$*					
	B (1) R: 422.8	OŚ (2) R: 341.9	OB (3) R: 285.8	PŚ (4) R: 396.6	PB (5) R: 297.9	N (6) R: 333.1
B (1)	X	0.124	0.001*	1.000	0.001*	0.069
OŚ (2)	0.124	X	0.364	0.344	1.000	1.000
OB (3)	0.001*	0.364	X	0.001*	1.000	1.000
PŚ (4)	1.000	0.344	0.001*	X	0.001*	0.184
PB (5)	0.001*	1.000	1.000	0.001*	X	1.000
N (6)	0.069	1.000	1.000	0.184	1.000	X
Sum of ranks	26217.5	42400.5	36011.0	57912.0	36045.5	34316.5

B (1) – goalkeeper; OŚ (2) – central defender; OB (3) – side defender; PŚ (4) – central midfielder; PB (5) – side midfielder; N (6) – striker; * level of significance $p < 0.05$

Table 5. Difference in players' age among the formations (Kruskal-Wallis test)

Dependent: players' age in the formations	The value of the Kruskal-Wallis test $H = 53,233$ $p = 0.001$*					
	B (1) R: 442.1	OŚ (2) R: 382.8	OB (3) R: 306.9	PŚ (4) R: 374.3	PB (5) R: 255.9	N (6) R: 327.8
B (1)	X	0.797	0.001*	0.348	0.001*	0.004*
OŚ (2)	0.797	X	0.001*	1.000	0.001*	0.520
OB (3)	0.001*	0.034*	X	0.074	0.627	1.000
PŚ (4)	0.348	1.000	0.074	X	0.001*	0.961
PB (5)	0.001*	0.001*	0.627	0.001*	X	0.102
N (6)	0.004*	0.520	1.000	0.961	0.102	X
Sum of ranks	27410.5	47474.0	38679.0	54650.0	30969.5	33720.0

B (1) – goalkeeper; OŚ (2) – central defender; OB (3) – side defender; PŚ (4) – central midfielder; PB (5) – side midfielder; N (6) – striker; * level of significance $p < 0.05$

Table 6. Distance covered by the players among the formations

Formation	Distance covered during a game		
	First half (m)	Second half (m)	Entire game (m)
B (1) ($\bar{x}$ ± SD)	2049 ± 293 ^{2,3,4,5,6*}	2133 ± 391 ^{2,3,4,5,6*}	4183 ± 647 ^{2,3,4,5,6*}
OŚ (2) ($\bar{x}$ ± SD)	4696 ± 310 ^{1,3,4,5,6*}	4697 ± 392 ^{1,3,4,5,6*}	9394 ± 623 ^{1,3,4,5,6*}
OB (3) ($\bar{x}$ ± SD)	5080 ± 336 ^{1,2,4,5*}	5080 ± 340 ^{1,2,4,5*}	10160 ± 596 ^{1,2,4,5*}
PŚ (4) ($\bar{x}$ ± SD)	5539 ± 366 ^{1,2,3,6*}	5497 ± 410 ^{1,2,3,6*}	11036 ± 695 ^{1,2,3,6*}
PB (5) ($\bar{x}$ ± SD)	5436 ± 430 ^{1,2,3,6*}	5430 ± 449 ^{1,2,3,6*}	10867 ± 788 ^{1,2,3,6*}
N (6) ($\bar{x}$ ± SD)	5161 ± 398 ^{1,2,4,5*}	5149 ± 476 ^{1,2,4,5*}	10310 ± 734 ^{1,2,4,5*}
Total ($\bar{x}$ ± SD)	4908 ± 1016	4904 ± 1007	9813 ± 1990

B (1) – goalkeeper; OŚ (2) – central defender; OB (3) – side defender; PŚ (4) – central midfielder; PB (5) – side midfielder; N (6) – striker

* the numbers in superscript are the variables for which the differences between the means is statically significant at $p < 0.05$

covered a distance of 9813 ± 1990 m. This distance was very symmetric when taking into account the two halves of a match, which was found to be 4908 ± 1016 m in the first half of the match and 4904 ± 1007 m in the second half (Tab. 6).

Significant differences were found in the covered distance among the team formations, as evidenced by the high value in the Kruskal-Wallis test, at $H = 395.963$. The longest distance measured during the matches was by central midfielders, at 11 036 ± 695 m, and was significantly longer when compared to the other analyzed formations. In addition, side midfielders also covered significantly longer distances, at 10 867 ± 788, than the players in the other formations (except central midfielders). The specificity of playing as a goalkeeper meant that these players covered on average the shortest distance during matches, at 4183 ± 647 m. Among the outfield players, the shortest distance covered during the games was by central defenders, at 9394 ± 623 m, while strikers, at 10 310 ± 734 m, and side defenders, at 10 160 ± 596 m, were found to be quite similar to each other (Tab. 7).

Analysis made on the two halves of the games did not find (except for goalkeepers) any significant differences among the analyzed groups of players. A significantly longer distance, of more than 4%, was found in players playing as goalkeepers in the second half of a game (Table 2). In both halves of the game, the longest distance measured was by central midfielders, in the first half at 5539 ± 366 m and in the second half at 5497 ± 410 m, and side midfielders, in the first half at 5436 ± 430 m and in the second half at 5430 ± 449 m. Besides goalkeepers, the shortest covered distance during the two halves of the game was found in central defenders, who covered 4696 ± 310 m in the first half at and 4697 ± 392 m in the second half (Tab. 8 and 9).

The strength of association between the covered distance and body height was found to have a value of $r = -0.42$, while the covered distance and body mass was $r = -0.45$, pointing to average correlation. It has been found that athletes characterized with greater body mass and height, in other words those who have a more massive figure, frequently cover shorter dis-

Table 7. Difference in the entire distance covered by the players among the formations (Kruskal-Wallis test)

Dependent: distance covered in the formations	The value of the Kruskal-Wallis test $H = 395{,}963$ $p = 0.001$*					
	B (1) R: 31.1	OŚ (2) R: 177.9	OB (3) R: 326.5	PŚ (4) R: 507.6	PB (5) R: 470.4	N (6) R: 356.2
B (1)	X	0.001*	0.001*	0.001*	0.001*	0.001
OŚ (2)	0.001*	X	0.001*	0.001*	0.001*	0.001
OB (3)	0.001*	0.001*	X	0.001*	0.001*	1.000
PŚ (4)	0.001*	0.001*	0.001*	X	1.000	0.001
PB (5)	0.001*	0.001*	0.001*	1.000	X	0.001
N (6)	0.001*	0.001*	1.000	0.001*	0.001*	X
Sum of ranks	1953.0	22063.5	41149.5	74118.5	56928.5	36690.0

B (1) – goalkeeper
OŚ (2) – central defender
OB (3) – side defender
PŚ (4) – central midfielder
PB (5) – side midfielder
N (6) – striker
* level of significance $p < 0.05$

Table 8. Difference in the distance covered during the first half of the game among the formations (Kruskal-Wallis test)

Dependent: distance covered in the formations	The value of the Kruskal-Wallis test $H = 390{,}823$ $p = 0.001$*					
	B (1) R: 31.5	OŚ (2) R: 180.8	OB (3) R: 328.2	PŚ (4) R: 509.1	PB (5) R: 465.7	N (6) R: 354.1
B (1)	X	0.001*	0.001*	0.001*	0.001*	0.001*
OŚ (2)	0.001*	X	0.001*	0.001*	0.001*	0.001*
OB (3)	0.001*	0.001*	X	0.001*	0.001*	1.000
PŚ (4)	0.001*	0.001*	0.001*	X	1.000	0.001*
PB (5)	0.001*	0.001*	0.001*	1.000	X	0.001*
N (6)	0.001*	0.001*	1.000	0.001*	0.001*	X
Suma of ranks	1957.0	22425.5	41353.0	74338.0	56361.0	36742.5

B (1) – goalkeeper
OŚ (2) – central defender
OB (3) – side defender
PŚ (4) – central midfielder
PB (5) – side midfielder
N (6) – striker
* level of significance $p < 0.05$

Table 9. Difference of the distance covered during the second half of the game among the formations (Kruskal-Wallis test)

Dependent: distance covered i n the formations	The value of the Kruskal-Wallis test H = 354,323 p = 0.001*					
	B (1) R: 31.3	OŚ (2) R: 195.7	OB (3) R: 332.7	PŚ (4) R: 491.9	PB (5) R: 464.2	N (6) R: 356.7
B (1)	X	0.001*	0.001*	0.001*	0.001*	0.001*
OŚ (2)	0.001*	X	0.001*	0.001*	0.001*	0.001*
OB (3)	0.001*	0.001*	X	0.001*	0.001*	1.000
PŚ (4)	0.001*	0.001*	0.001*	X	1.000	0.001*
PB (5)	0.001*	0.001*	0.001*	1.000	X	0.001*
N (6)	0.001*	0.001*	1.000	0.001*	0.001*	X
Suma of ranks	1953.0	24278.0	41924.5	71826.5	56179.5	36741.5

B (1) – goalkeeper
OŚ (2) – central defender
OB (3) – side defender
PŚ (4) – central midfielder
PB (5) – side midfielder
N (6) – striker
* level of significance $p < 0.05$

Table 10. Dependent correlations between the distance covered and the players' somatic characteristics and age

Distance covered	Somatic characteristics and age			
	Body height	Body mass	BMI	Age
R value	–0.42*	–0.45*	–0.25*	–0.24*

* level of significance $p < 0.05$

tances. A similar conclusion was stated when using the BMI index. When this value was correlated with the distance covered, it was fond to be $r = -0.25$, which therefore signified a low degree of correlation, but significant at $p < 0.05$. Similarly, the correlation between age and covered distance was also found to be at $r = -0.24$, also pointing to a low degree of correlation, but significant (Tab. 10).

Discussion

In order to achieve success in modern sport, not only does training need to begin at an early age but it is necessary to have knowledge on the genetic determinants that shape an athlete. Body composition, anthropometric measurements and morphological characteristics all play an important role in achieving sporting success [17]. The analysis conducted by the authors found that the present generation of elite European football players have higher body height and lower BMI than players in the Spanish [18], Croatian [19] and Portuguese [20] football leagues at the beginning of the new millennium. This increased body height found among the players also correlates across the entire male population [21].

The values of the tested morphological characteristics as well as the age of the players were found to be significantly different among the various studied formations. Goalkeepers were found to have significantly higher values of age when compared to the players of the other formations. The largest body mass in the analyzed tournament was also that of goalkeepers, as well as of central defenders, which corresponds to previous studies [4]. Undoubtedly, this is associated with the greater technical and tactical requirements of outfield players. Such close relationships between these formations have also been found in the English and Spanish leagues, while the mean body mass of the players who took part in the European Football Championships was also close the body mass of players in the German league [22].

The distance covered, especially when correlated with the morphologic characteristics, which themselves are largely genetically determined, may be a criterion towards determining what formation a player should play in by fully taking advantage of their energy capabilities [11, 23]. Previous studies have found that the longest distances covered during a match are by midfielders, while players that form the offense and defense decidedly less so [1, 24, 25].

On average, the distance covered by the players in the analyzed tournament was found to be 9813 m, which is less than the distance covered by the player in professional European leagues, which was found to be 10 800 m [26] and by players in the Brazilian First division, at 10 024 m [1]. However, it must be taken into that account that the mean distance covered, as found in this study, was lowered by the inclusion of the distance travelled by goalkeepers. If the players of this formation were omitted, than the mean distance covered would have been 10 432 m.

It was found that, generally, the players in the first half of the game covered a distance larger than in the second half, at 5520 m and 5250 m, respectively [26]. This was also confirmed in another study, where the mean distance covered in a match was 10 860 m, where in the first half it was 5510 m, while in the second half, 5350 m [23]. The players in the analyzed tournament were found to have covered distances very similar to the ones above, in the first half at 5213 m, while in the second, at 5219 m.

The results of the study also found that the distance covered on the field by the players also significantly varied depending on what formation they played in. The longest distance among the analyzed European players was by center midfielders, at 11 036 m, and side midfielders, at 10 867 m, while in a study performed on the Brazilian First division, this was found to be held by side defenders, at 10 642 m, and only then by side midfielders, at 10 589 m, and central midfielders, at 10 476 m [1]. The mean shortest distance of the players was found in both studies to be held by strikers and central defenders. In this way was the analysis conducted on the players of European leagues confirmed [26].

It appears that the distances covered by the players during the 2008 European Football Championships were optimal when taking into account the intensity of the game, which ranged from 80% to 90% of maximum capacity and took place during a game lasting 90 minutes. Physiologically, it would be impossible to maintain a higher mean intensity for a longer period of time due to the accumulation of lactic acid in the blood and increasing fatigue [27].

Conclusion

It was found that the highest values of body mass, height, age and the BMI index were among the players who play as goalkeepers. Among the football players of the other formations, significant differences were found in the values of the studied somatic characteristics.

The longest distance covered in a game was by those football players who are central and side midfielders, while the shortest distance covered, outside of goalkeepers, was by central defenders. Significant differences were also found among the various formations.

Players with greater body mass and height covered shorter distances during the games. A similar occurrence was found, though with less significance, in the case of age and the BMI index.

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CHANGES IN BODY COMPOSITION AFTER ENDURANCE TRAINING AND TRIATHLON COMPETITION

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ABSTRACT
Purpose. The aim of this study was to investigate the effects of training and triathlon competition on anthropometry, plasmatic free fatty acids (FFA) and hydration status. **Methods.** Twelve male triathletes were submitted to a 12-week training program to compete in the "32° Pirassununga Half Ironman". Anthropometric measurements such as skinfold thickness and bioelectrical impedance (BIA) as well as urine and blood samples were collected at three intervals: at the beginning of the training program (M-1), before (M-2) and after competition (M-3). FFA were analyzed using a NEFA-C kit. Urine pH and density was determined using reagent tapes and a manual refractometer. Data were analyzed using one-way ANOVA and the Tukey-Kramer post-test ($p < 0.05$). **Results.** No differences were found for body mass (M-1 = 71.83, M-2 = 74.22, M-3 = 72.15 kg), percent body fat using skinfolds (M-1 = 10.98, M-2 = 10.92, M-3 = 10.40%), urine density (M-1 = 1.02, M-2 = 1.01, M-3 = 1.02) and urine pH (M-1 = 6.00, M-2 = 5.92, M-3 = 5.35). For BIA and FFA, differences were found after competition (BIA: M-1 = 13.54, M-2 = 13.91, M-3 = 9.45%; FFA: M-1 = 0.16, M-2 = 0.15, M-3 = 1.69 mEq/L). **Conclusions.** These results illustrate the effects of training and competition on body composition and FFA mobilization. Additionally, after five hours of effort, no evidence of dehydration was found after the race.

Key words: body composition, endurance training, hydration and triathlon

Introduction

The triathlon is a sport that consists of swimming, cycling and running performed sequentially one after the other. Since its emergence in the late 70s, the distances of the different parts of triathlon were changed. Currently, the International Triathlon Union (ITU) recognizes official events as those with distances ranging from 0.75, 20 and 5 km for swimming, cycling and running in the short triathlon, to 3.8, 180 and 42 km for the Ironman competition, respectively.

According to Hausswirth et al. [1], triathlon training and competition can result in changes in the hydration status of athletes in the sense that dehydration may be dangerous when the athlete loses more than 7% of body weight during training and competition [1, 2]. Changes in body mass may also be due to liquid release from skeletal muscles and the liver during strenuous effort due to glycogen oxidation [2–5]. Therefore, changes in body mass are a result of modifications in body composition induced by the training program and the hydration status during the training program and competition [2].

In a study done by Sharwood et al. [6], 872 athletes participating in the 2000 and 2001 South Africa Ironman showed significant reductions in body mass after the competition and this effect was attributed to liquid release, as well to the consumption of energetic substrates during the race. Sharwood et al. [7] also found reductions in body mass in seventeen triathletes after an Ironman, however, the objective of the research was to correlate body mass with performance indicators and blood sodium concentration in each segment of the competition. They concluded that weight loss correlates with blood sodium concentration, which apparently is a good indicator of dehydration after long-term efforts.

Knechtle et al. [8], studying athletes participating in the Deca Ironman World Championship (38 km swimming, 1800 km cycling and 420 km running divided across ten consecutive days), found reductions in body mass with maintenance of fat free mass and reduction of fat mass. Similar results were found in the Hew-Butler et al. [9] study with 181 athletes during the 2000 South Africa Ironman. In another study, Knechtle and Kohler [10] studied 17 athletes who were competing in the 2006 Triple Iron ultra-triathlon in Germany (11.6 km swimming, 540 km cycling and 126.6 km running), no differences in body fat were found at the end of the competition. The same author, while studying the same group of athletes, detected

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reductions in body fat by skinfold thickness when this variable was correlated with race intensity [11]. Knechtle et al. [12], in a case study performed during the Deca Ironman World Championship, detected reductions in percent body fat by skinfold thickness in an athlete that completed the competition in the third place. In this case, fat consumption was attributed to the distance and elapsed time during the competition (128 h 22 min 42 s), as well the energetic cost estimated for this competition (89112 Kcal).

In the study by Knechtle et al. [8], bioelectrical impedance analysis (BIA) was also used to estimate the percent body fat of eight athletes after a Deca Ironman competition, where it was possible to identify reductions in percent body fat after the race. In a similar study by Knechtle and Kohler [10], reductions in percent body fat by using BIA were found after an ultra-triathlon. According to Farber et al. [13] and Gerth et al. [14], intense endurance exercise causes the mobilization of fat from storages in the liver, skeletal muscle and subcutaneous tissue to provide for the energy used during the effort, consequently, reducing the water content within the cell.

Knoepfli et al. [15] studied the blood free fatty acids (FFA) concentration during a 25 km running test. The results revealed a significant increase of FFA from the beginning of the test, suggesting the participation of this substrate in order to make up for the energetic cost of this activity. In the case of the Hausswirth et al. [1] study, nine athletes were evaluated in three different exercise situations to estimate the energy cost of running. The first trial was a simulated triathlon with a similar distance to official Olympic events, the second was a 2 h 15 min run and the third a 45 min race at an average intensity used in the run segment of triathlon competitions. Although in all of the conditions the plasma FFA concentrations increased significantly, in the second exercise trial it was found to be higher, probably due to the time spent performing the activity and the amount of performed cyclic movements.

Long distance sports such as the triathlon commonly cause reductions in total kidney blood flow and this effect seems to be related to exercise intensity [16]. The major factor associated with this exercise effect is catecholamine release, causing a constriction of blood vessels and a reduction in the glomerular filtration ratio, and in the case of exercise-induced dehydration, the glomerular filtration ratio may also be further reduced [16].

Currently, few studies have devoted to understanding body composition changes (body mass and percent body fat and hydration) in triathlon athletes in pre-race training programs and after a long-distance competition. In this sense, the main purpose of this study was to verify the effects of a twelve week training program in body composition, FFA mobilization and hydration status in an attempt to understand the acute changes in body composition and hydration after long term efforts.

At the beginning of this study, we hypothesize that during the training program, changes would occur in body composition, reflected by body mass and percent body fat without changes in hydration status of athletes. Immediately after competition, it was expected to find modifications of all variables of body composition, as well as the increased availability of plasmatic free fatty acids and the incidence of dehydration, which would be indicated by changes in both the urinary density and urinary pH.

Material and methods

Twelve male triathletes volunteered to participate in the study. They signed an informed consent waiver and were submitted to the experimental protocol according to the design of the study. The anthropometric characteristics are provided in Table 1. They were submitted to a 12-week training program composed of 20% of interval training and 80% of continuous training. They were evaluated at the beginning of the training season (M-1), before the competition (M-2) and 30 min after the "Pirassununga Half Ironman" (1.8 km swimming, 90 km cycling and 21 km running) (M-3). The procedures and techniques proposed in this study were approved by the ethics committee of the School of Physical Education and Sport of the University of Sao Paulo.

Table 1. The anthropometric characteristics of the triathletes

N	12
Age	32.6 ± 5.1 years
Sex	male
Training Experience	6.5 ± 4.9 years
Race Time	5 h 07 min ± 38 min

Body mass was determined using a digital balance (PL200, Filizola, Brazil). Skinfold thickness was obtained using a skinfold caliper (HSB-BI, Baty International, UK) and the Jackson and Pollock [17] equation was used to estimate percent body fat. Finally, bioelectrical impedance analysis (BIA) was performed by using a tetrapolar body analyzer (BF-900, Maltron International, UK).

Urine and blood samples were also collected at the beginning of the training season, before the competition and 30 min after the Half Ironman. Blood samples were obtained by antecubital vein puncture into 10 mL tubes containing EDTA. After collection, the samples were stored in ice and transported to the laboratory for further analysis. Urine was collected into universal collectors and stored in ice and then transported to the laboratory and analyzed.

The FFA concentration was determined by using a Nefa C kit (Wako Chemicals, Germany). The assay consists of a colorimetric enzymatic reaction, producing a violet compound that was quantified by spectrophotometry in a SpectraMAX Plus (Molecular Devices, EUA) at 550 nm against a calibrator.

The results obtained were analyzed with the GraphPad Prism (Graphpad Software, USA) statistic software package. Data were submitted to the Shapiro-Wilk normality test and ANOVA for repetitive measurements followed by the Tukey-Kramer test, where differences were considered significant at $p < 0.05$.

Results

The results found for each variable studied in M-1, M-2 and M-3, and the *p*-values for the statistical comparisons are shown in Table 2.

For the first measurement (M-1), body mass was found to be 71.83 ± 7.42 kg, at M-2 to be 75.52 ± 5.99 kg and at M-3 to be 72.15 ± 5.58 kg. Percent body fat, estimated by using the skinfold thickness method was 10.98 ± 7% at M-1, 10.62 ± 7% at M-2 and 10.40 ± 6.63% at M-3. When using BIA, percent body fat was 13.54 ± 1.17% at M-1, 11.54 ± 1.39% at M-2 and 9.45 ± 2.73% at M-3. Differences were found for this indicator when M-3 was compared to the other collected samples. The results are presented in Figure 1.

Blood samples collection revealed free fatty acids concentration (FFA) to be 0.16 ± 0.11 mEq/L at M-1, 0.15 ± 0.08 mEq/L at M-2, and 1.69 ± 0.61 mEq/L at M-3. Differences were found when the result obtained at M-3 was compared to the other measurements. The results are presented in Figure 2.

Urine samples collected showed no modifications in the hydration indicators such as urine density and pH during the training program and after the Half Ironman. Urine density was 1.02 ± 0.005 g/ml at M-1, 1.01 ± 0.01 g/ml in M-2 and 1.02 ± 0.008 g/ml at M-3. Urine pH was 6.00 ± 0.53 at M-1, 5.92 ± 0.83 at M-2 and 5.35 ± 0.41 at M-3. The results are presented in Figure 3.

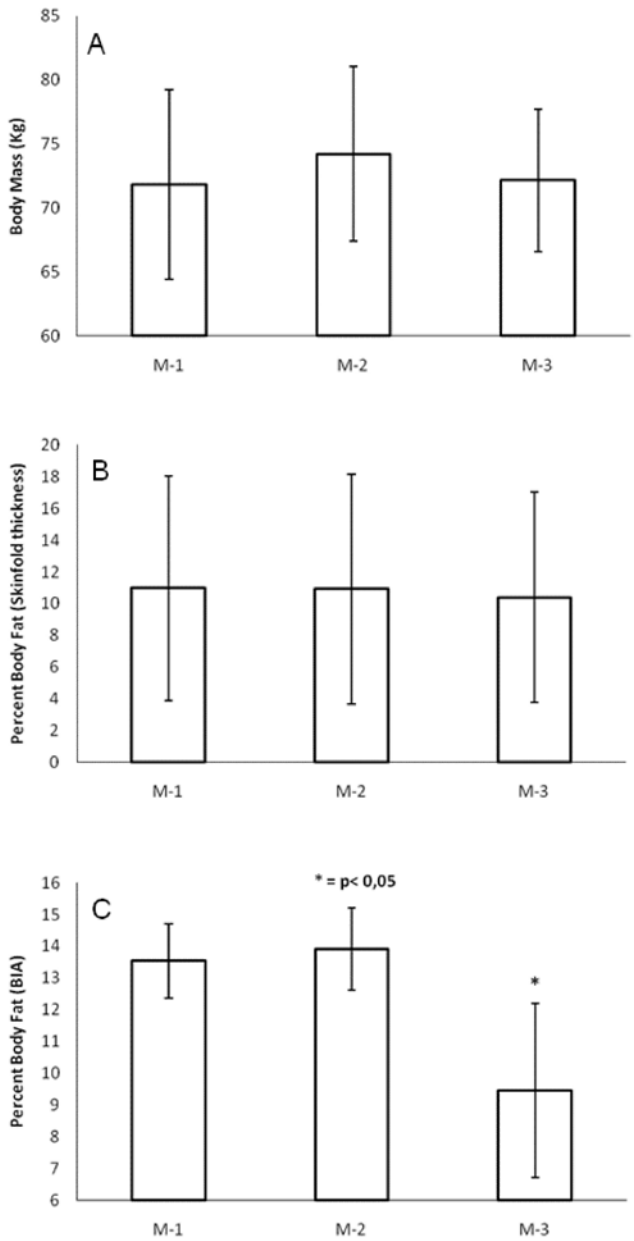

Figure 1. Body mass (A), percent body fat using the skinfold thickness method (B) and percent body fat using BIA (C) at the beginning of the training program (M-1), before the competition (M-2) and after the Half Ironman (M-3), * $p < 0.05$

Table 2. Results obtained for each variable studied during the experimental protocol. Data are expressed in mean ± standard deviation and * indicates statistical difference when compared to the other collection times

	M-1	M-2	M-3	*p*
Body Mass (Kg)	71.83 ± 7.42	75.52 ± 5.99	72.15 ± 5.58	0.5410
Percent body fat (skinfold thickness)	10.98 ± 7.00	10.62 ± 7.00	10.40 ± 6.63	0.9972
Percent body fat (BIA)	13.54 ± 1.17	11.54 ± 1.39	9.45 ± 2.73*	0.0001
AGL (mEq/L)	0.16 ± 0.11	0.15 ± 0.08	1.69 ± 0.61*	0.0001
Urine Density (g/ml)	1.02 ± 0.005	1.01 ± 0.01	1.02 ± 0.008	0.4591
Urine pH	6.00 ± 0.53	5.92 ± 0.83	5.35 ± 0.41	0.0571

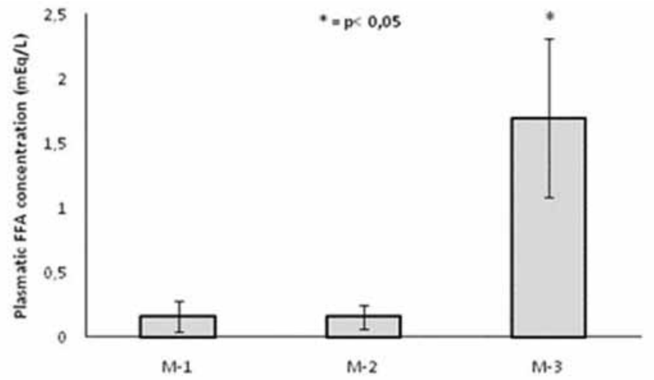

Figure 2. Plasmatic FFA concentration (mEq/L) at the beginning of the training program (M-1), before the competition (M-2) and after the Half Ironman (M-3)
* $p < 0.05$

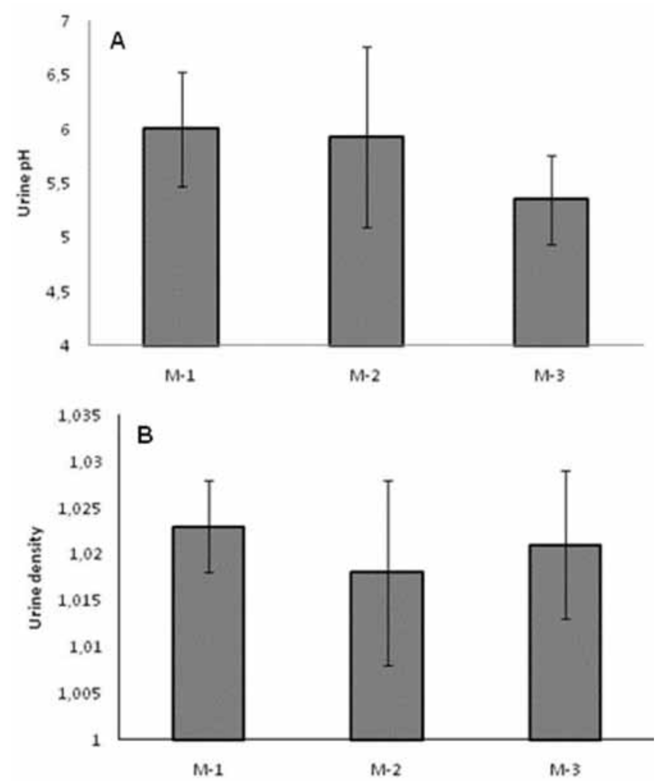

Figure 3. Urine pH (A) and urine density (B) at the beginning of the training program (M-1), before the competition (M-2) and after the Half Ironman (M-3)

Discussion

The main findings of this study was the change in percent body fat measured using BIA, where the skin fold thickness method was not sensitive enough to detect the change after competition. Another important finding was the maintenance of hydration indicators through urine analysis, contrary to the expectation that a long-term triathlon race would induce significant liquid release due to the performed effort.

Body mass changes generally are the result of a training program and hydration status in endurance athletes [2]. According to Laursen et al. [2], Sawka and Coyle [3], body mass changes also occur due to liquid release by the liver and skeletal muscles during glycogen oxidation to provide for the expenditure of energy. Our results revealed no reductions in body mass during the training program and after the Half Ironman competition, which was different to the results reported in literature [1, 2, 5, 9, 18, 19], where longer events such as an Ironman, a Triple Iron ultra-triathlon and a Deca Ironman were studied. Therefore, it is possible to argue that the results found in the cited studies are the result of the energetic demand imposed by long-distance competitions, as well external variables such as hydration strategies, humidity, atmospheric pressure, temperature and nutrient supplementation during the competition. In this study, the maintenance of body mass was attributed to the distance of the event, as well as to the liquid and substrates consumption during the Half Ironman. In this sense, it is possible to deduce that body mass is not a reliable indicator to be used alone to study body composition and hydration status of athletes.

The finding that skinfold thickness did not reveal differences is very similar to the results found in the literature [10]. These data indicate that muscle glycogen and triacylglycerols are important substrates to supply energy when compared to subcutaneous sources of fat [2]. In another study of Knechtle et al. [11], changes in percent body fat percentage by skinfold thickness were found when this variable was associated with the intensity of the event, as well the intramuscular liquid loss promoted by the degradation of the energy sources. Another case was found in a case study of Knechtle et al. [12] performed in the Deca Ironman World Championship, when reduction in percent body fat, measured by skinfold thickness, was detected in an athlete that finished third in the competition. Once more, the subcutaneous fat consumption was attributed to the distance and the time of the competition (128 h 22 min 42 s), as well the energy cost estimated for the competition (89112 Kcal).

From the data observed in the studies cited above, it is possible to argue that in the present study, the maintenance of percent body fat measured by using skinfold thickness occurred due to the time and energy elapsed during the Half Ironman. However, in the percent body fat measured using BIA, we observed reductions in percent body fat at M-3. These data are very similar to those found by Knechtle et al. [8], were BIA was also used to assess percent body fat before and after a Deca Ironman. In this case, the differences are explained by the increased training volume (M-2) and fatty acids mobilization from the muscles and liver storages, caused by the training and the Half Ironman (M-3). This assumption explains why the skinfold thickness was not sensitive enough to detect the modifications in body composition, since this method is based on the estimative of body fat in subcutaneous deposits.

Similarly to the other studies reported in literature [1, 15, 18, 20], the results found in the present study revealed a significant increase of FFA after the race. Here it is possible to argue about the participation of substrate fatty acids during the energetic expenditure imposed by aerobic effort. In the Hausswirth et al. [1] study, nine volunteers were evaluated in three different situations to estimate the energetic cost of running. Despite the experiments, plasma FFA concentration was significantly increased and probably caused by the time spent during the effort and amount of cyclic movements performed during the experiments. In the present study, a significant increase of plasma FFA concentration was found after the effort, probably induced by endocrine factors such as a release in catecholamine and cortisol (data not shown).

We expected to find evidences of dehydration after the Half Ironman by using urine density as a marker of hydration status. According to Clerico et al. [16], renal blood flow is reduced during physical effort and this effect is related to the intensity of the exercise. Apparently, this effect reflects sympathetic nervous system activity and catecholamine release, inducing a reduction in kidney blood flow and in the glomerular filtration ratio. In the case of dehydration due to long-term physical effort, the glomerular filtration ratio can be further reduced. In this study, urine density and urine pH showed similar responses during both the training season and competition. When these results are taken together, they confirm the hydration status of the athletes during the testing conditions. The present results confirm the results of previous studies when the athletes did not demonstrate evidence of dehydration [5].

In the present study, no evidence of dehydration, as measured by using both urine density and urine pH, was found. These results can confirm the data obtained by using BIA after the competition and collaborate with the findings of Pastene et al. [5], where even with the weight loss after an endurance effort, the hydration status did not change, probably due to the athletes using an appropriate hydration strategy during the race. From the present results obtained after the competition, we can observe that the 112.9 km effort of a Half Ironman promoted reduction in body fat of the athletes without signs of dehydration (Fig. 1 and 3).

Conclusion

This study illustrates the important effects of a training program through the reduction of percent body fat, measured by using BIA, and in the increase of plasma free fatty acids availability caused by the Half Ironman. Another important contribution is that approximately five hours of effort did not affect the hydration status of the athletes when this indicator was assessed by measuring both urine pH and urine density. Despite the changes found in body composition, it is important to note that body mass did not significantly change during the entire experimental protocol. Some practical implications of this study are that, from the results obtained in this study, we would like to suggest a revision of the interchanging uses of measuring body composition methods. The previous recommendations for using BIA do not guarantee measurement accuracy, since the decrease in total body water, not representing dehydration, need to be revised. Finally the obtained results in this study suggest that FFA mobilization is specific and not generalized.

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THE INFLUENCE OF THE "RED WIN" EFFECT IN SPORTS: A HYPOTHESIS OF ERRONEOUS PERCEPTION OF OPPONENTS DRESSED IN RED – PRELIMINARY TEST

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ABSTRACT
Purpose. Psychological research indicates that, in contact sports, the results of sports competitions might be influenced by the color of an athlete's uniform (especially the color red). However, previous research has not yet experimentally verified whether this hypothesis might be a consequence of perceptual distortion caused by moving objects of a certain color, such as red. Therefore, the aim of this study was to determine the effect of an object's color on the efficiency of performing simple tasks in a basic computer game. **Methods.** 225 participants aged between 16 and 30 years played nine different "arcade" games of skill, differed by the rules and colors used in the game, where the subjects were tested on their ability to hit, escape from, or outmaneuver certain objects of a certain color (either blue, red or black). The score achieved was then correlated to what effect the color of the objects had on a subject's visual perception. **Results.** It was found that the study participants were able to hit red moving objects significantly better than blue and black objects. No difference was found in the ability to avoid elements, in all three colors. **Conclusions.** The obtained result finds that in some games of skill, the color of the used stimulus might significantly influence perceptual efficiency and, therefore, the results and performance of individuals. The results of our study suggest that future research is needed in investigating the meaning and role of colors, as this may be very important, in various sports. The colors used in sports equipment, uniforms, environment, etc., should be empirically verified if they can influence the results of sports competitions.

Key words: sport, color, "red win effect", agility, cognition, gender differences

Introduction

Interest in the influence of color on the psychology of human functioning might have had a long history, but (up to the end of the last century) little has been achieved in terms of empirical research. An example of this would be the research performed on the color red. For many years different studies have suggested that the color red symbolizes fire, energy, passion and love, with it standing as a metaphor for war, madness and rage. Within such a context, it was expected that the color red ought to stimulate or excite the human organism [1]. However, the vast majority of experimental studies have not confirmed this assessment [2, 3]. It is for this reason that the most recent studies on this phenomenon are of considerable importance, in which it was found that the color red affects the human motivational process [4–7], can act as a distraction [8], or influence the perceived attractiveness of sexuality in humans [9–11]

One of the main aspects of psychologists' research on the color red is the effect it has on the functioning of an athlete. The aim of this study presented here is in verifying one of the mechanical hypotheses on the impact of sportswear's color on the results of sports competition. Literature on the subject includes several existing studies on this topic [12–24], which mostly relate to the color black or red. Probably the first of these experimental studies was conducted by Frank and Gilovich [12]. They found that NHL and NFL players who had black as their team color were more often punished for aggressive game behavior when compared to players in different team colors. They also found that there exists a stereotype of a team wearing black being portrayed as the "bad, aggressive" one. The observers also found aggressive behavior more prevalent if the "aggressor" (athlete) was dressed in black, as well as finding that if the "aggressor" (especially within a group of individuals) was dressed in black, he acted even more aggressively than when if he were dressed in a different color [12].

Several years ago, Hill and Barton [14] initated a new wave of research on the impact of color in sports uniforms in competition, this time with the color red. As is well known, during Olympic boxing, taekwondo, classic wrestling and freestyle wrestling competition, the player's uniform color (red or blue) is randomly selected. Thus, the number of wins by players in blue should be, throughout an entire tournament, similar to the amount of wins scored by players in red uniforms. More specifically, the frequency of wins by those in "red" or "blue" should not differ significantly

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from a random value of 0.5. However, as was demonstrated by Hill and Barton, during the Olympic Games in Athens in the above mentioned disciplines (totaled all together) the ratio was 0.55 to 0.45 in favor of those dressed in red ($p < 0.03$). The effect of "red win" was even stronger when the fight could be considered even, where one of the competitors succeeded with a small point win in favor of the "red" opponent (0.62 to 0.38; $p < 0.005$). Hill and Barton argued that the effect of "red win" is based on a biological-evolutionary foundation. The color red and red-tinted skin or the adornment of "red ornaments" in many animals is associated with both gender and the level of testosterone that signifies the male quality [25, 26]. Therefore, having "red ornaments" (even artificial, as sports attire) could work as a stimulant, increasing the "will to fight", the strength of desire for domination, etc. All of this can have a real bearing on the results obtained in sports competition.

However, translating the obtained results by the above researchers [14] is a bit troublesome within the context of various ethological studies, which find that male dominance in animals can in fact be experimentally increased by attaching artificial red stimuli to them [27], but which does not add or prove anything to its male quality. Moreover, the results of research performed on animals' senses found that mammals, other than chimpanzees, did not show any signs of self-consciousness (for example, in recognizing themselves in a mirror) [28, 29]. Finally, in a study by Hackney [30] where the testosterone levels of humans wearing red and black shirts were measured, it was found that simply wearing a colorful shirt did not increase the testosterone levels of anyone tested. This suggests that the explanation of the effect as proposed by Hill and Barton may in fact be incorrect. It seems that the cause of this phenomenon is located in the "observer" (the opponent of the "red rival") rather than in the one adorned in any red decorations. Seeing a "red rival" apparently causes some sort of process in the "observer", a process that reduces his chances of victory.

Therefore, a plausible hypothesis would be that the effect of "red win" is a consequence of "rival intimidation", with the biological reasoning behind this being that the "red rival" might be more dangerous, brave, dominant, etc. This hypotheses is supported by research performed by Elliot et al. [4], who demonstrated the impact of color on the efficiency of solving certain mental tasks. A subject's visual exposure to a red stimulus decreased their mental problem solving ability (anagrams) as well as performance in IQ tests. The authors suggested that the reason for this reduction in mental ability was conditioned motivation: a red stimulus blocks the motivation to achieve and activates the desire to avoid. As has been found [4], after concentrating on a red stimulus, subjects often preferred easier tasks to harder ones. In addition, EEG measurements found that a red stimulus induces a stronger activation of the right rather than the left frontal lobe of the brain, and, in accordance with the findings of Davidson et al. [31], this asymmetry gives prominence to the desire to avoid. Thus it was demonstrated that the color red (through the processes of motivation) might affect the efficiency of processing information. It is therefore likely that the color red may also effect the efficiency of performing fundamental motor functions. However, as of now, no studies have been conducted that clearly confirm the above stated hypothesis in sport.

Another explanation that goes against Hill and Barton's [14] proposal is a process where color is used to assess a fight by a referee [21]. The effect of "red win" may be a consequence of that fact that the "red" player may seem to be to the observer (the referee) stronger, more aggressive, faster, etc., and this causes, especially when there is an evenly matched fight, to identify him more as a winner during a fight, and therefore, award him more points. Such a hypothesis is quite plausible within the context of Hill and Barton's [14] results, in which the amount of winners in red was particularly high in fights that were evenly matched. It is exactly in such fights were the points awarded by referees explicitly decide who the winner is, and what is more, in the case of a de facto tied score in some disciplines (e.g. wrestling), the referee choses the winner based on the more combative player.

This hypothesis, confirmed by Hagemann et al. [21], found that referees who kept score in the same taekwondo match, during an experiment in which the competitors changed their uniform color, awarded an average of 13% more points to the "red" rather than the "blue" players. This result also seems to be consistent with the results obtained by Sorokowski and Szmajke [18], where test subjects had to choose which boxer they wished to hypothetically fight against, one in a red and one in a blue shirt. The color of the shirt did not significantly influence the choice of opponent. However, there was influence on the trend-level of assessing the bravery and aggressiveness of the boxers (the boxer in the red shirt was evaluated as more brave and aggressive than the one in a blue shirt), even though there was no measured influence on the assessment of the supposed boxers' technical skill or physical characteristics (strength, endurance). The above mentioned hypothesis was also indirectly confirmed by a simple experiment in which a test presented two circles, one red and one blue [32]. In this study the red circle was rated as more dominant and aggressive.

In subsequent studies, attempts were made to verify the universality and repeatability of the results previously obtained by Hill and Barton [14]. It seemed unlikely that simply dressing up in a red or black outfit (for example: chimney sweeps or Santa Claus) could have any effect on their bravery, aggressiveness or dominance. Yet the question stood, does this effect in fact occur in every form of individual and team competition, such as in boxing, golf and chess? Presently, there is no convincing evidence confirming the existence of the "red win" effect in team sports, at least in football. Although it is true that Attrill et al. [23], in presenting data from the English Football League from 1947 onwards, as well as analysis of match results when the English team wore white and red team uniforms, did suggest that this effect is present in football; however, two similar studies did not confirm this effect in the Polish [17] and German [24] League.

It is also worth noting that the effect described by Frank and Gilovich [12], on the impact of athletes' black uniforms on aggressiveness, was not confirmed in an analysis of matches in the Turkish Football League [16]. Instead, the study suggested that the impact of a uniform's color on people could only be understood within a context of rivalry (including sports) as well as in a confrontation that had elements of aggression. In the case of the sports effect of the "red/black win", this could be in the domain of sport where there is a direct fight between only two opponents. It also needs mentioning that research performed on the universality of this phenomenon did present another hypothesis that could explain its functioning. Rowe et al. [15], when examining the reliability of Hill and Barton's results [14], found that judo players in blue won more often than those dressed in white. While it is true that the results of Dijkstra and Preenen [22] indicated that this result [15] could have been caused from that fact that, at least in the initial rounds of the judo match, the uniforms' colors were not allocated randomly as well as being linked to other variables, such as the length of rest between the matches, however, further analysis by Matsumoto et al. [19] confirmed Rowe et al.'s data [15]. Matsumoto, besides being psychologist, was also a former athlete and is now a world-class referee and coach. In addition, his study was published in the Research Journal of Budo, giving credence to its reliability. In explaining another hypothesis that could explain this phenomenon, these researchers [15, 19] suggested that the effect of color on winning may in fact be a consequence of disrupting the perception of moving objects in a certain color. Certain colors, more than others, could be more conducive in making errors in the perception of moving objects. Rowe et al. [15] suggested that this has to do with the contrast of the background on which the objects are perceived. According to this hypothesis, the effect of "red win" is due to the fact that an opponent of a "red" team commits minor errors in their perception of the "red" team's speed, distance, etc., which may be very relevant in elementary sports skills and therefore cause the player competing against an opponent in a red uniform to lose.

However, this hypothesis, that the effect of "red win" may be a consequence of perceptual disruption of moving objects in red has not yet been experimentally verified. Therefore, the study presented in this article will attempt to verify this hypothesis and also test the effects of the colors blue and black. The aim of this study is to determine the effect of an object's color on the level of efficiency of performing low-skill tasks performed in a computer game.

Material and methods

110 women aged between 16 to 26 years (M = 18.45, SD = 1.6) as well as 115 men aged 16 to 30 years (M = 20.21, SD = 2.4) took part in the study. The respondents were overwhelmingly high school students and university students (studying various subjects). The subjects were randomly assigned into nine research groups (N = 25 for each group), where each group had three different arcade games to perform on a computer, where the effect of objects, in this case, balls, in three different colors were tested (blue, red and black) (see Fig. 1).

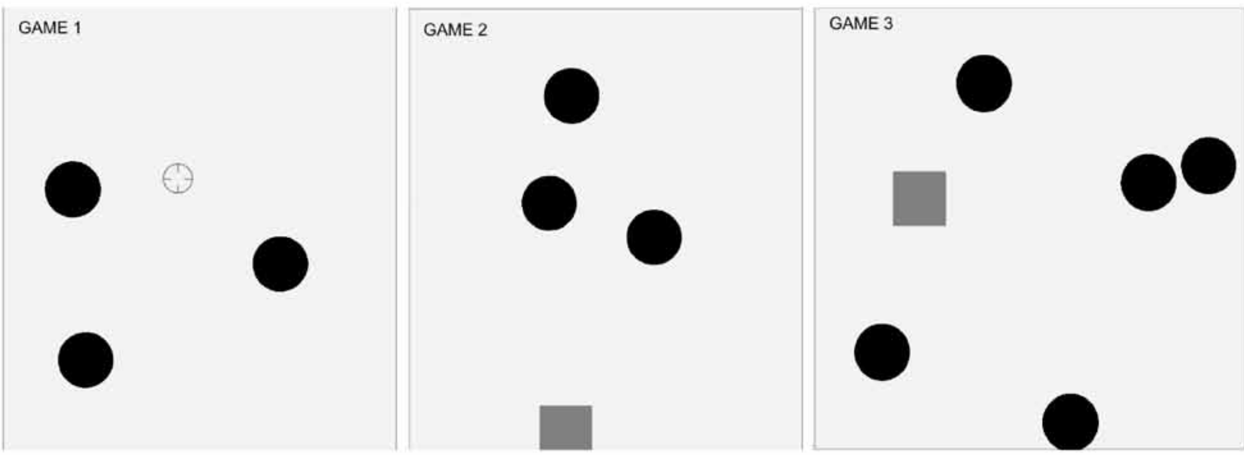

Figure 1. An example of the three games' layouts used in this study

Each of participants in the first phase of the game took part in a trail round, in which they were informed about the rules of the game. In the trial round, in order to be neutral, each of the balls in the groups were white. The subjects then took part in one of three games, the details of which are described below (which, as mentioned, differed from each other by the colored balls: red, blue and black). The visual background in all of the games was a very light beige color. For each game, the board size was approximately 19 × 14 cm. In all of the games, the players were able to move, depending on the goal of the game, a square around the board by using four arrow keys (▲, ►, ▼, ◄). The study was conducted on a computer laptop with a 15.4" glossy screen (BrightView), set at a resolution of 1280 × 800 pixels. The subjects were tested independently in separate rooms, however they were each guaranteed quiet testing conditions as well as similar lighting conditions. The three games used in the study were as follows (see also Figure 1):

Game 1. In this game, colored balls with a diameter of 2 cm "fell" from the top to the bottom of the board, with their rate of movement increasing with each successive second (total game time: 60 s). The location of the balls starting at the top of the board was randomly selected (i.e., each of the succeeding balls that appeared in at the game). The direction of the balls' movement was entirely random (either more "left" or more "right" or straight down). The object of the game was shooting down as many balls as possible, in other words, by aiming a "sight" at the moving balls using the arrow keys and shooting it down by hitting the space bar on the keyboard. The intention of the authors was for the game to represent an easy way to simulate attempts at hitting objects of a certain color.

Game 2. Here, colored balls with a diameter of 2 cm "fell" from the top to the bottom of the board, with their rate of movement increasing with each successive second (total game time: 60 s). The location of the balls starting from the top of the board was randomly selected (i.e., each of the succeeding balls that appeared in the game). The direction of the balls' movement was entirely random (either more "left" or more "right" or straight down). The player had to direct a square that was fixed at the bottom of the board either right or left and "avoid" being hit by any of the falling balls. The intention of the authors was for the game to represent an easy way to simulate attempts at escaping/evading objects of a certain color.

Game 3. This game also had colored balls with a diameter of 2 cm start "falling" from the top as well as from the right and left of the board. The balls' rate of movement increased with each successive second (total game time: 60 s). The location of the balls starting from the top and sides of the board was randomly chosen (i.e., each of the succeeding balls that appeared in the game). The direction of the balls' movement was entirely random. The player had to direct a square, which could move across the entire board (up, down, left and right), and the goal was to escape from as many of the falling balls as possible. The intention of the authors was for the game to represent an easy way in simulating an escape/evade attempt before being hit by objects of a certain color, which "attack" the player from different directions.

Results

For each of the individually played games, one way ANOVA analysis was performed on the results as a set of 3 (the color of the objects, i.e., balls) × 2 (subjects' gender).

Game 1 – *hitting a moving object of a specific color*

The dependent variable in the first test was the number of balls that were "shot down" by the study participants. Analysis found that the gender of the participants was significant $F(1, 69) = 15.5$, $p = 0.0002$), specifically, that men (M = 47.7, SD = 9.8) shot down more balls than women (M = 40.8, SD = 11.2). Also, the color of the balls also was found to be significant ($F(2, 69) = 3.2$, $p = 0.04$). Post-hoc LSD tests (least significant difference) found that the subjects were able to shoot down more red colored balls (M = 44.7, SD = 10.8) than blue (M = 38.4, SD = 12.1) or black ones (M = 38.5, SD = 10.4) (with *ps* at least < 0.04) (see Fig. 2). Interactive significance, when calculating for "ball color × subjects' gender", was not found (F(2, 69) = 0.4, $p = 0.7$).

Game 2 – *escaping/evading objects of a certain color*

The dependent variable in the second test was the number of balls that the test subject failed to "escape" from. Analysis found that the gender of the participants did not have any significance ($F(1, 69) = 2.0$, $p = 0.2$), nor was there significance of the balls' color ($F(2, 69) = 0.3$, $p = 0.8$) (see Fig. 2) or interactive significance of "ball color × subjects' gender" found ($F(2, 69) = 0.4$, $p = 0.7$). Also, no significant differences were found in the above mentioned results in post-hoc tests (LSD test, *ps* > 0.1).

Game 3 – *escaping/evading objects of a certain color, which "attack" the player from different directions*

The dependent variable in the third test was the number of balls that the player failed to escape from. Analysis found that the gender of the participants was significant ($F(1, 69) = 2.0$, $p = 0.2$), finding that men (M = 31.9, SD = 6.5) "escaped" from more balls than women (M = 38.2, SD = 15.6) (which also means that

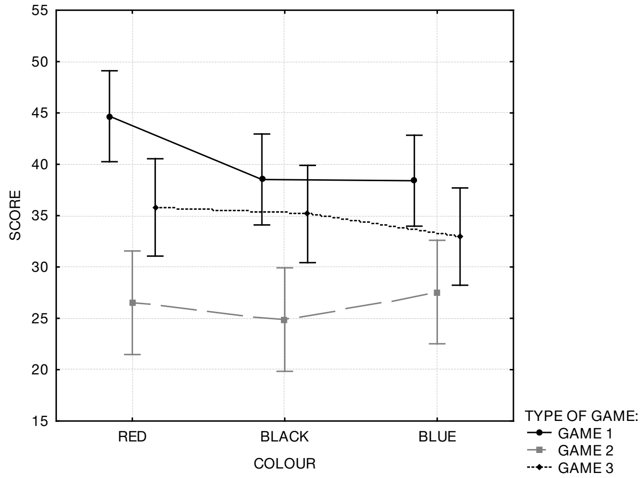

Figure 2. The efficiency level as a function of the objects' color

men were hit by a smaller number of balls). No significance was found in the balls' color ($F(2, 69) = 0.5$, $p = 0.6$) (see Fig. 2), as well as any interactive significance for "ball color x subjects' gender" ($F(2, 69) = 0.2$, $p = 0.9$). For these two effects, no significant differences were also obtained in post-hoc tests (LSD test, *ps* > 0.08).

Discussion

The obtained results indicate that in certain types of action/skill games the color of any stimuli can significantly affect performance efficiency. It was found that the study participants are more likely to hit moving objects that are red in color than objects that are black or blue. However, there was no difference found in the number of objects that the study participants had to effectively escape from. Thus, the obtained results are inconsistent with the originally mentioned research hypothesis; they do not explain the proposed effect of "red win" by Hill and Barton [14]. In addition, in light of the results presented in this study, the effect of "red win" occurs despite the fact that, in all reality, it is easier to "hit" objects that are red rather than another color. This suggests that, in real contact sports, an athlete's red uniform ought to facilitate rather than impede their rival.

However, what was found in this study is not sufficient enough evidence for the total rejection of the originally proposed hypothesis. The cause (observed in actual sports competitions) of the relationship between a uniform's color and the final game score could be the result of conditional errors (differences) made in the perception of moving objects of a certain color. Colors have different properties, including different wavelengths (the wavelengths of red and orange are considerably longer than, for example, the wavelengths of blue and green), different frequency (the frequency of red is lower than in other colors) or other physical characteristics such as the reflectance of each color (an overview of this is found in [33]).

All of these parameters can affect, for example, the rapidity of perceptually recognizing objects in different colors, which has been confirmed in experimental studies. It was found that red and purple are perceived, in a horizontal perspective, earlier than the colors black, blue or green [34]. Therefore, it cannot be definitively ruled out that the opponent of a "red/black/blue" player might not commit minor errors in their perception of their rivals' speed, distance, etc., which may be relevant in fundamental sports performance. The results of our study only suggest that, in a confrontation with a "red rival", it is unlikely that losing to a player in red would be a consequence of perceptual errors or that the opponent in a red uniform is more difficult to hit (the study results suggest quite the opposite). However, our results do not exclude the possibility that red sportswear might not cause one to commit other perceptual errors. The results obtained in this study appear to be important and interesting even though they did not confirm the originally stated hypothesis. First of all, this study is one of few that confirmed the significant impact of color in performing simple low-skill tasks. Generally, the effect of color on the performance efficiency of certain activities has not been fully explored, and in those studies that attempted to study this phenomenon, the results of some (due to the used procedure) are difficult to interpret [35] or found that color has no effect on fundamental motor tasks (e.g., catching cricket balls of different colors) [36].

We feel that our results are of some practical importance. These results are a further confirmation of the data presented earlier [14, 15, 19, 21], suggesting that the random assignment of colored uniforms may not be entirely fair. The basic principles of fair play state that at the beginning of a competition, each of the opponents must be entirely equal and provided with equal opportunities. The experimentally confirmed effect of color on the outcome of a sport/game, in our opinion, justifies the need to change the rules of some sports so that the results obtained by athletes are as objective and fair as possible. Discussions on this issue have already occurred in some sports disciplines. For example, the International Judo Federation (despite opposition from the Japanese Federation) decided in 1997 that one of the players in a fight will be required to wear a blue judogi. Some suggested that this change be preceded by research on the possible impact this might have on athletic performance [37]. After several years, we now hold data that states that the change of the judogi's color did in fact have an effect on athletic performance ("blue winning against white"). Therefore, judo federations and other sports federations should make use of the latest scientific research and perform their own similar analysis (for example, it would be worthwhile to see if the red uniform of a target shooter does not in fact distract other opponents).

The presented study has shown that color can affect the perception of moving objects, which may then affect the performance level of completing certain tasks (e.g., aiming, hitting objects of different colors). Therefore, the results of our study justify increased interest in the study of color's importance in various sports disciplines as well as the experimental verification of whether and how color affects or how color may affect (such as clothing, equipment, surrounding environment, etc.) competition results. This appears to be of particular importance when worldwide sports federations are enacting numerous changes in the rules, equipment, etc., of a game to make it more visually appealing as well as increase the viewership of certain disciplines.

Some of these changes, perhaps unintentionally, resulted not only in changes of the disciplines' colors (literally), which could have had, as was reported in this study, a significant impact on the cognitive processes and motivation of players, eventually affecting their performance. It is evident that when making such decisions, one should be aware of all possible effects, and the results of research on the various issues raised in this article should provide relevant premise. For example, recently in volleyball, the official ball used in the most important tournaments classified as "world-class" changed to the Mikasa ball, which is blue-yellow. Previously, the ball used in these types of games was the Molten, which sports red elements. This change was made for purely marketing reasons, with no one checking whether the Molten ball with its red elements was easier for players' perception (in light of the results of this study, the red elements of the ball ought to have made it "easier to hit"). Therefore, there are reasons to believe that this change could have adversely affected the quality and continuity of the game (e.g., with fewer digs or blocks). What is more, all of these changes occurred at a time when the world's volleyball authorities introduced special changes in the rules of the game to make playing defense easier.

A significant difference revealed in this study that finally needs mentioning was the difference in the results of men and women, as found in Games 1 and 3. This is not an unexpected result. Several studies have demonstrated the differences between genders in a variety of simple fitness tests [38], especially those that require hand-eye coordination (catching or stopping a flying ball, throwing objects at a target, etc.) had men perform far more successfully (a review can be found in [39]). However, in the case of the study presented here, we suggest that the observed differences are related primarily to the fact, as has been demonstrated in several studies, that men more often and are more likely to play computer games [40, 41]. Therefore, it can be said that the boys and men who took part in this study had a higher probability of having more skills and experience in computer games, which may have influenced the results of this study.

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BASKETBALL PLAYERS' PERCEPTION OF THEIR COACHES

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ABSTRACT
Purpose. The aim of this study was to analyse Spanish women basketball players' perception of their coaches in order to discover whether this perception is different from those in other sports and which character traits are the most appreciated in the sport of basketball. **Methods.** We administered a questionnaire survey in December 2010 to a total of 65 Spanish national division basketball players, where they were asked to evaluate their coaches with a set of 10 adjectives, rating them on a Likert seven-point scale with 1 being the least favourable and 7 the most favourable. **Results.** The results find that the players have a generally positive opinion of their coaches' personal qualities, although there were some small differences in the evaluation of what might be called "professional" qualities, which were not as high. Traits such as honesty (6.01), friendliness (5.97) or self-confidence (5.43) had higher values than imagination (4.3), dynamism (4.9), intelligence (5.1) and other attributes which could relate more to technical aspects or methods of training. With regard to the totality of the scale, the mean was found to be 5.22, with the maximum value being 6.01 for honesty and the lowest for imagination at 4.3. None of the analysed adjectives received a negative rating by the players. **Conclusions.** This study finds that women basketball players have an overall good perception of their coaches, as based on the analysed sample. These results are very similar to previous findings in other sports. In addition, they rate "personal" features with a higher score than traits that could be considered "professional" and, therefore, be an opinion of job performance.

Key words: behaviour, values, motivation, performance, team sports

Introduction

In order to optimize the performance of a team in any sport, it is important to know the perception that players have of their coach. Fulfilling goals that had been set at the beginning of the season will have largely to do with the players maintaining the correct and desired assessment of their coach.

More than three decades ago Smith et al. [1] developed a study that analysed the relationship of American League baseball players and their coaches. The leadership model that was developed shortly after [2] was designed to examine the influence of the behaviour of coaches of youth teams and concluded by noting that both the personal characteristics of coaches and players influenced the perception of the coaches on the attitudes of their players and, additionally, in determining their response to them. As such, these characteristics also influenced the perception that the players had of their coach. That same year, Rushal [3] found that coaches should be a reference model for their athletes, providing an image of reliability, consistency and constancy.

Subsequent studies have confirmed what was expected: the players' perceptions of their coach greatly influence the realisation of team goals through an improvement of certain team aspects [4]. Thus, if the player feels understood by their coach, team harmony improves [5], or if he or she notices some form of social support, this leads to a greater degree of satisfaction [6–9]. Isberg [10], in a study conducted on Swedish athletes, observed that they preferred a communicative coach that they could trust and one that gave them real opinions about their performance as well as provided constructive criticism. Reversely, if the player holds a negative image of their coach, they may feel insecure and worried, thus affecting their future performance [11].

Although the importance of this perception has been demonstrated, it is necessary to consider which characteristics make up a player's image of an ideal coach. These characteristics will undoubtedly vary from one sport to another. Among the studies conducted to date, fair play and other social values were the more important features as observed in research by Orlick [12], while Rushal [3] defended that reliability, consistency and perseverance, among others, were important. Cunha et al. [13] concluded that, in football, the most important characteristics of a coach are responsibility, honesty, friendship, work capability and an open mind, among others. Other studies pointed to sincerity, self-confidence, honesty and intelligence as the characteristics most valued in the same sport

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[14, 15], while the lowest valued were those of sportsmanship, awareness and friendliness [15]. In the case of basketball, Rolla [16] designed a study which concluded that the perception of the players varied depending on their category and level of competition, without reaching firm conclusions on which could be considered the best features that could lead in improving overall team performance.

This study aims at analysing the perception of women basketball players competing in the Spanish national first division have of their coaches and then comparing these values with those obtained in other sports. The aim is to discover whether this perception is different from other sports as well as which characteristics are the most valued by basketball players.

The main hypothesis is that these characteristics are similar to those of other team sports and that the players would prefer a "friendlier" coach more than a "professional" one. If this theory is confirmed, it might influence the realisation of team goals through more adaptive training strategies based on changes of a coach's demeanour.

Material and methods

The study participants were 65 women basketball players, all of whom played in the Spanish national first division in Madrid. Since the total number of players for the 2009–2010 season was around 150 (with slight variations due to changes during the season), the sample is considered more than significant. All of the players are considered to be at an amateur level as established by authorities on the subject [17]. Ages ranged between 18 and 34 years old, with the mean age being 23.4 years.

The questionnaire designed for the study was adapted from a modified version of the original Portuguese Player Coach Interaction Inventory [18–20]. It was developed by its authors and included a total of 80 questions that were given to the respondents in a random manner so that the order did not have any influence on the answers. These questions evaluated the image that players had of their coaches on the basis of player--coach interaction. After analysis of the answers, a series of 10 adjectives were used to characterize the coaches, where each one was rated on a Likert seven-point scale, with 1 being the least favourable and 7 the most favourable. Finally, the overall result was obtained by adding the partial scores, which ranged between 10 and 70. The adjectives selected were: honest, friendly, fair, communicative, confident, imaginative, dynamic, intelligent, motivated and experienced. In the same questionnaire demographic data on age, sex and other information relevant to the study was included.

The internal consistency was analysed by Cronbach's alpha coefficient, yielding an overall value of 0.95 for the entire scale, ensuring the reliability of the questionnaire. Validity was also examined by principal components analysis confirming that it correctly measured what it was intended to measure, with 71% of variance accounted for values over 1. With regard to the sensitivity of the scale, this was measured through analysis of the normal distribution, finding that it was not normal. This does not invalidate the results, and is in fact consistent with previous studies done in soccer, indicating that a possible reason for this may be the population's homogeneity of the rated attributes [15]. For statistical analysis the mean, standard deviation, minimum and maximum values were calculated for each of the adjectives of the questionnaire and for the entire scale, considering the sample as a whole. Statistical analysis was performed using computer software (SPSS version 15.0, IBM, USA).

The various clubs of the women's basketball division, known as the "first national", all located in the Community of Madrid, were all consulted and asked for acceptance to conduct the surveys. Except for one club, which never answered the request, the remaining accepted the survey proposal without reservation either by telephone or e-mail. The survey was conducted in December 2010. All of the questionnaires were distributed and completed prior to training on a weekday and in the afternoon. Players were informed both verbally and in writing (in the questionnaire itself) about the objective of the study. In addition, the coaches were previously informed on the day chosen for the survey so as not to interfere with any scheduled training, due to questionnaire taking approximately 10–15 minutes to complete.

Results

The results find that players have a fairly good perception of their coaches within the personal sphere, although there were some small differences in the valuation of what might be considered "professional" characteristics, where they were not valued as high. Honesty (6.01), friendliness (5.97) and self-confidence

Table 1. Results on a 0–10 scale for the characteristics of coaches as perceived by players

Characteristics	Mean	SD
Honest	6.01	1.21
Friendly	5.97	1.20
Fair	5.38	1.12
Communicative	5.11	1.18
Confident	5.43	1.13
Imaginative	4.30	0.98
Dynamic	4.92	1.04
Intelligent	5.10	1.09
Motivated	4.95	1.07
Experienced	4.96	1.11

(5.43) had higher values than imagination (4.30), dynamism (4.92), intelligence (5.10) and others which could be construed as being associated with the technical aspects of a coach or even their performance in training sessions. With regard to the totality of the scale, the mean was found to be 5.21. The maximum rated value was 6.01 for honesty, while the lowest was 4.30 for imagination. None of the adjectives analysed received a negative rating by the players.

Discussion

Almost all the current studies to date find that coaches were rated positively giving credence to the globality of the surveys [15, 16]. In this study, the mean value can be also described as positive, although slightly lower than in other study results. In a detailed analysis of each adjective, the results largely coincide with those recorded for football by Rosado et al. [15], where some of the most valued characteristics were sincere, confident, honest and motivated, while among the least valued were those describing coaches as a good athlete or mindful. The most important differences between the two studies were the rankings of intelligence and friendliness. Intelligence differed not only as an absolute value (5.94 in Rosado et al. versus 5.1 in this study), but especially in its position when ranked among all of the values. Friendliness (valued at 5.69 in Rosado et al. vs. 5.97 in this study) also ranked differently when sorted by score among all of the other values.

The characteristic of friendliness is especially important, as Seller et al. [21] endorsed in their study, as it is essential in achieving high performance in sport. Other researchers, such as Botterill [22] and Raposo [23], also indicate the importance of this characteristic, stating that a coach must take into consideration athletes' personal situations and not only be concerned with purely sport aspects in order to improve their performance.

The characteristics that obtained the highest scores on the scale could be considered "personal" in relation to the rest, which could be classified "professional". This, in part, was corroborated by the results obtained in other team sports by Isberg [10], where confidence, communication and dialogue were the most valued, by Cunha et al. [13], who marked honesty as the most valued, or by De Marco et al. [14], for whom friendliness, sincerity and honesty were ranked as far more important than technical knowledge or coaching experience. Similarly, Salminen and Liukkonen [24], in a study of 400 athletes, found that coaches who cared about the opinions and feelings of their athletes had better ratings. In addition, no reference was found in the mentioned literature where technical or "professional" aspects of coaches were rated higher than "personal" characteristics.

It appears that the current image of a basketball coach is more like a friend than a professional. In all of the research performed up to now, it was found that players prefer someone who is honest and interacts in a friendly behaviour rather than a very good professional that perhaps does not convey confidence. Therefore the question arises as to which approach used by coaches is better or worse. In order to do so, different coaches with different personalities should be analysed in a longer study. In addition, it would be beneficial to analyse the effects of change in a coach's personality, however, it would be highty difficult in finding a willing test subject. Nonetheless, this is perhaps one of the more interesting lines of future investigation that need to be developed.

Conclusion

This study finds that women basketball players have a good perception of their coaches. They rate "personal" features with a higher score than "professional" features, which could be an opinion of job performance. The best possible coach has to be, in their opinion, friendly, honest, confident and fair. It is therefore reasonable to suggest that coaches should try to develop a more personal approach, rather than a professional approach, towards their coaching in order to achieve the best possible results. However, this needs to be confirmed with additional research.

The results should also be confirmed by analysing the possible changes over the playing season, as well as with other studies that establish differences as based on the players' years of experience with the current coach. It would also be desirable to provide analysis of other amateur team sports in Spain, such as football, handball and volleyball, as well as individual sports, like athletics, where some differences may be found in the most valued characteristics of coaches due to the idiosyncrasies of the performed sports.

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THE FREEDOM OF THE BODY IN THE SEMIOTICS AND PHILOSOPHY OF SPORT

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ABSTRACT
Purpose. The aim of this paper is to define the meaning of sports world records, which to attain require long years of strenuous training, within the sphere of humanistic and cultural values. The differences between newly placed records and previous scores are usually centimetres or hundredths of a second, which hardly contribute to the spectacularity of a competition. Is therefore setting a record more meaningful as a cultural, not a sports, goal? **Methods.** A semiotic-pragmatic method was used in this research. The method was founded on C.S. Peirce's semeiotics, which is a sign theory based on the triadic, relational concept of signs. Every sporting event, every individual achievement of an athlete is a sign, which acquires meaning due to its interpretation and being part of the so-called process of semiosis. **Results.** The popularity and cultural meaning of particular sports does not result from the immanent features of a sporting competition, such as its aesthetic merits or the dynamics of the game. The differences in times of the best runners in a prestigious 100 metre race are unperceivable to the human eye. The attraction stems from cultural factors, which are meaningful in the sphere of values of a given culture. One of such values in which sport relates to it is freedom. **Conclusions.** Striving for records, even at the cost of one's health, has (for the sports described in the article as contesting) a motivation in the cultural (philosophical) meaning of overcoming the limits of the human body's physical abilities. Every record set means that those limits have not yet been reached and therefore are still unknown. This spiritual freedom is accompanied by the equally vital, as confirmed by records, sense of physical unlimitedness.

Key words: philosophy of sport, pragmatism of sport, semiotics

Introduction

Freedom is one of the most important values in Mediterranean culture. Broadly understood, both in the spiritual and material sphere, freedom can be connected with the personal dimension of our existence as well as with the general conditions which have defined the functioning of groups, nations, social systems and cultures throughout centuries. However, defining freedom is not simple and usually requires a broad humanistic context and, in particular, a reference to a multitude of various philosophical concepts[1]. I assume that freedom, above all, is a value realised individually and one which all rational beings are equally entitled to having. By definition, freedom cannot be limited by factors differentiating people in an accidental or physical way. No human being deserves freedom in life any more or less on account of their place of birth, sex, physique, skin colour, etc. We declare that in our European (western, northern) culture, freedom is an inalienable and irreducible value; it constitutes a sanctity that is fought for, because it is a necessary condition of a dignified and happy life, and in our axiological system, all which is done for the sake of freedom, for one's own or others', is evaluated positively.

In the human dimension of decision-making, freedom can be opposed to determinism, which in this context assumes that "[...] all our mental states, together with choices and decisions, and all deeds, are results that been conditioned by previous reasons. As an effect, our future is as much determined and immutable as our past. The truth or the falsity of this view depends on our nature, including physical nature, and not on our wishes or partialities" [1, p. 786]. In a philosophical perspective it is significant whether the choices of our will are initiated by an undetermined (free) way or are the effect of reasons extraneous to our will, which naturally do not have to be perceived by the subject. Even if we assume the lack of necessary reasons for our choices (indeterminism), i.e. we accept the freedom of will, it is hard to claim that a similar degree of freedom is enjoyed by our body, which, as we are convinced every day, is determined by the laws regulating material reality, a part of which it constitutes.

Do the records set in various sports have meaning in the discussion of freedom, especially while attempting to answer the question if our physicality is unequivocally determined and we can establish the limits of our abilities? Is freedom, in its physical dimension, a value represented in modern culture by sport or in sport? I adopt a research assumption that the answer to these formulated questions is connected with defining the *meaning* that sporting events, during which world records contesting the limits of human abilities are set, have in culture[2]. The methodology of my research is based on the semiotic method, i.e., I assume that the course of sporting events, the results achieved, the reactions of fans and commentators, etc., are signs that are subjected to further interpretations, going beyond a given sporting event, or even beyond sport in general. This type of methodology enables defining the effect (pragmatic) that sport has in the realm of broadly understood culture, including philosophy with its fundamental issues.

What should *physical freedom* be in a semiotic context and how is it connected with modern sport, whose results and records are particularly desired and valued? Although our free choices, in the sphere of intentions of our actions, can be evaluated as good or bad, or as worthy choices and unworthy choices, physical acts do not deserve neither praise nor condemnation on behalf of their physicality, as they seem to be rooted in the world of material laws which we cannot influence. The value of physical acts depends on their motives and the intentions which originated from them, which relates us back into the sphere of ethics and morality, where the body is subject to will and if will is not able to control the body than it does not take responsibility for potential deeds. Putting a loop of string around another human being's neck and depriving this being of life is an act accepted on certain conditions, at least in certain countries. Exactly the same series of physical actions can lead to *the defence of freedom* as well as to *a reprehensible crime*. This type of value is not autonomous and does not result from itself unless we assume that human life (understood as something broader than physicality) is an overriding value that cannot be used as a currency in any utilitarian give or take situation. Thus understood, physicality does not decide on anything, is subject to the reign of reason and will, and therefore its acts cannot be praiseworthy, dignified or eminent in themselves.

Can modern and contemporary sport be an effective argument against the above related reasoning? Is it an affirmation of physicality, which manifests itself in breaking records which have autonomous meaning and do not demand being related to the overriding role of will and reason, whose decisions and judgements, in opposition to physicality, can be deemed good or bad?

Material and methods

The analysis method that was adopted to study this phenomena within the arena of sport is semiotic-pragmatic and based on C.S. Peirce's (1839–1914) methodological-epistemological propositions[3]. This method enables defining the meaning (semiotics) and the interpretational consequences (pragmatism) of sporting events which appear, and gain further meaning, in all spheres of culture [6]. This type of methodology does not, by assumption, probe into the motives of actions of subjects engaged in doing and propagating sport, but analyses the state of affairs that can be universally observed, in which records, beaten by hundredths of millimetres and seconds, unperceivable to the human eye, gain meaning. World record holders in different sports are universally respected and often become signs of (mean) values which are not immanently connected with sport.

In the research perspective adopted by me, the records are significant on behalf of indeterministic interpretation, in which breaking the apparent limits of human abilities betokens physical freedom.

To avoid ambiguity, it is necessary to stress that Peirce's semiotic propositions used in this article substantially differ from *semiology*, which was being developed in Europe at the same time, in isolation from Peirce's study of signs. The creation of semiology is attributed to F. de Saussure (1857–1913) [7], for whom a sign was a diad, a link between the signified (*signifié*) and the signifier (*signifiant*), and the relations between them were psychological and non-necessary. Despite the fact that the terms semiotics and semiology happen to be used interchangeably, as two names for the science of signs [8], it happens that even with the basic essential question of what is sign, the above-mentioned researchers and their followers differ on basic theoretical issues[4]. Peirce's semiotic propositions are located in the field of logic (theory of relations) and scientific methodology, whereas de Saussure's semiological ones are in linguistics and psychology. The characteristic for Peirce's semiotics is the assumption that a sign is a *triadic relation*, which means that nothing is a sign unless it enters into relation with its *interpretant*, i.e., until it is interpreted as a sign. Each of the elements of a sign can be a self-standing sign in itself, demanding further interpretation. The process of interpretation, i.e., semiosis, is continuous, as an *interpretant* of a given sign is a subsequent sign, i.e. a subsequent triadic relation which is interpreted by a subsequent sign, i.e., a subsequent sign relation. This type of relational construction of a sign ensures interpretative continuity (synechism) which is clearly shown in rational thinking processes where, e.g., terms (signs) are defined (developed through other signs) and their definitions undergo further clarification or are changed under the influence of new facts which are *represented* by subsequent signs. A sign relation is divided triadically and trichotomically, which, as a consequence, leads to generating a series of formal classes of signs. A basic differentiation divides signs into icons, indexes and symbols, i.e., signs, the interpretation of which is based on the similarity of a sign to its object, the existential bond with it, or quasi-necessary relation created through reasoning (interpretation). For philosophy and semiotics of sport, it is significant that Peirce allows not only for conceptual or intellectual interpretation but also for an emotional and energetic one [10], which is primary and in this sense necessary before a further interpretative process may take place. It means that all reactions, such as commotion, joy, clasping and cheering are in a semiotic sense an interpretation of a given sporting event. Obviously, after the event finishes, these interpretations are continued, e.g., as media reports or in speeches given by fans, politicians, clergymen or philosophers, i.e., generally speaking, by all those who are interested in sport or what is represented by sport. In sign relations, sport can represent (stand for) any object if it becomes interpreted in that way. For example, for politicians, sport provides signs, the object of which are various *values* such as religious ones, which, however, have little in common with modern professional sport. For a philosopher of sport, through the usage of records, it can represent the idea of physical freedom as well as the ethical-moral principle of fair play or any other principle from the sphere of ethics and morality. This type of interpretation does not have to be based on personal participation in a sporting event, it can be the next step in which signs relating to sport can have, as part of their object, other signs, which have subsequent signs as their objects and interpretants, etc.; according to Peirce's semiotic propositions there is no limit on the number of layers in this kind of process of mediation and interpretation. There are signs currently functioning in culture that have become *semiotically cut out* of the interpretative process of sporting events, e.g. the so-called Kozakiewicz's gesture, which is sometimes interpreted as a symbol of the fight against the political order of the world at that time, against the dependency of Poland on the USSR, or due to a pain in the arm (as was publicized). I assume that similar semiotic processes related to sporting events where world records are set are meaningful in the philosophical discourse pertaining to the question of limits of physical freedom.

Results

The core of the research concerned about physical freedom in connection to modern sport a realised through sporting events – as I have already stressed in the context of C.S. Peirce's semeiotics and pragmatism – as proposed by me, is the division of sports into *performing* sports and *contesting* sports [11]. One of the fundamental criteria of this division is the method of sanctioning the results achieved during sport competitions, which implicitly stems from the valuation of truth in sport, where truth is understood as conformity between the sporting result and reality [12].

When reflecting on the broadly understood phenomenon of sport, there are different research perspectives and therefore there is no agreement as to the range of meaning of basic terms. J. Kosiewicz claims: "The terms 'physical culture' and 'sport, are interpreted in multiple ways. Sometimes – in a particular context of justification – they are understood as synonyms, whereas in other occasions they are presented as terms of different, sometimes even considerably different, content" [13, p. 8]. An extensive discussion concerning the nature of sport and the attempts at defining it, is presented and undertaken by S. Kowalczyk, who writes: "The term sport in an everyday intuitive approach is unambiguous, but in social appraisal and experience it is ambivalent. Sport can mean many different things and matters" [14, p. 28]. Lipiec, while analysing these complex methodological and terminological matters, claims: "The commonly used term 'physical culture' does not have positive associations, although it is hard to deny that it possess sufficient practical advantages. Speaking about 'physical culture', we more or less know what we are speaking about, despite the temptation to be ironic about bad pairing of both parts of the term. […] Enough has been written about sport to make this field a subject of a separate branch of knowledge. Today, the goal is not to answer the simple question 'What is sport?' (after all, from what position, arbitrarily, can we build such an explanation?), but to answer what are the various kinds of theories of sport, methodological schools, types of definitions and contexts, both scientific and cultural, for the essential study of sport" [15, p. 43, 47].

Thus, in proposing my own division of sports, I perceive at least two main streams of reflection on sport up to now. The first is concerned with terminology and defining what sport is and here exists the possibility that researchers using different terms denote similar phenomena. In the second, there appear attempts to describe the motives which cause people to take up activity denominated as sport. It can be the need to compete, play, have fun, fulfil the needs of a human being, etc.[5] "In a clear majority of the definitions of sport, relating – directly or unconsciously – to the prototypical vision of sport as a game (or any other game-like human confrontation), competition is pointed as being a constituent factor. Although the majority of sporting events actually takes place on the background of competition (usually between individuals, let us add), there are events which are undoubtedly of a sporting character, and yet without an element of competition which in turn is devoid of a sporting character sensu stricto" [15, p. 49].

The division into *performing* and *contesting* sports that I propose is not an attempt at defining the essence of sport or the motivation of people connected with sport. It is, however, true that sport regularly questions the limits of physicality that have been so far reached by beating existing records. However, if this is to take place in a way that does not leave place for doubt, it is necessary to precisely fulfil the certain formal conditions of competition which resemble the conditions of a scientific experiment and have to be rigorously pertained to during important sporting events. During the course of a sporting event, and, consequently, for its validity and correctness, refereeing, which sanctions its results, is crucial. Tolerating refereeing mistakes is being increasingly objected to, which is especially seen well by the milieus of fans and commentators. Is the only problem, however, as it is often presented, the irrational reluctance by sports authorities towards the introduction of technical innovations which will improve the quality of refereeing? The 2010 FIFA World Cup proved again that refereeing mistakes truly influence the course of a tournament, thus significantly contributing to the process of picking a winner. In the World Cup's England-Germany match, the referee did not accept a goal, which he probably did not see, scored by the English team at the end of the first half, when Germany was winning 2:1. One can speculate what consequences on the morale and further game of the English team would have been had a tie been called; a tie that they truthfully deserved. As a consequence of this manifest error by the referee, the English team was eliminated and Germany advanced to the finals. How is it possible that in times when even the most minute form of cheating on the part of an athlete is stigmatized and usually leads to invalidating the achieved result and to disqualification, that these kinds of refereeing decisions, creating a falsified sporting reality, are fully tolerated and accepted by people in charge of the competition?

Not all refereeing methods are as susceptible to these type of mistakes as in football, which is located on one end of the scale of tolerating refereeing mistakes. The other end of the scale is occupied by marathons, jumping events, swimming, especially during sporting events such as world championships or the Olympic games, which are sports where refereeing methods are rigorous and parallel to the controlled conditions of scientific experiments. The truth, understood as the concordance between the course of a sporting event and a referee's decision, for the part of sports which I call *performing*[6], is not a significant factor influencing the course of a sporting event. In the case of a refereeing mistake, two situations are possible: the mistake has been perceived by observers in the course of the game, or the fact that it was made was discovered only later, while analysing replays. During a football match (to the end of 2010) even if the observers, including the referee's superiors, immediately perceived the incorrectness of a decision, it could not be changed from the outside, because a referee during a match has full autonomy over choosing what he considers true.

Performing sports are usually competitive team or contact sports as well as martial arts, such as boxing. A significant outcome of such sporting events can take on three values: a conclusion (victory or failure) or lack of conclusion, i.e., a draw. In a football match, like in other team sports, the most important achievement is defeating the rival and not scoring a record number of goals or points. The World Cup Finals, where of only one goal is scored during the game chooses the winner just as much as a match where eleven goals are scored. The number of goals or the style of the game may have a meaning as far as the spectacularity of the sport and additional semiotic processes are concerned, especially the processes initiated in the setting of people professionally connected with sport, but it is insignificant as far as picking the winner is concerned. In team sports, records have a statistical character, e.g., a given team has not lost a match for several games, always wins in their own stadium, etc. Faultless refereeing and full adherence to the rules of the game is not an absolute in performing sports, as the scrupulous intervention of a referee negatively influences the dynamics of the game, e.g., either lengthening it and stopping an industriously worked out opportunity to score a goal, which could potentially choose the winner. A performing sporting event is a unique act, which occurs irrevocably. If a competition has taken place in the presence of hundreds of millions of spectators, it is hard to expect that this type of a sporting event will be made invalid and the winner deprived of his victory. The accent of *meaning* is moved from the truth of the achieved result to the *act of occurring* of a sporting event, sanctioned through the decisions of a referee. The deepest sense is granted to performing sporting events by their uniqueness and finality resulting from the unrepeatability of place, time and result, where "a sporting performance is an important cultural event, essentially influencing social and individual lives" [19, p. 261]. However the course of a game is not a result of an accident (the throw of a dice) in the sense of a lack of determinants which define the result of the game. It also does not stand for the aleatorism of sporting events. According to Kosiewicz: "From the point of view of basic formal assumptions, a sporting spectacle contains aleatory characteristics similar to those of certain musical compositions or theatrical shows. However the differences, both in the areas of constant, predictable elements are random ones, are too obvious and so basic that they are not even comparable. This is true of their structure and function, as well as teleological concepts, i.e. purpose, meaning the message conveyed by their content and merits. […] It should also be added that the internal structure of a musical spectacle or theatrical show does not contain the concept of competition or victory of certain elements included in the score or game plan" [19, p. 266].

Contesting sports (mostly individual) apply scientific methods to the evaluation of the course of the competition, and the conditions of an agon (classic sporting event) resemble a scientific experiment, in which factors which influence the result are strictly controlled. Special attention is paid to the athlete's organism, because during the competition human physicality is contested. Each record, preceded by years of strenuous training, removes a previously established limit in the efficiency of a given sport, consequently proving that our body's limits have not yet been finally established, yet at the same time further recognized where it lies. Is there, therefore, a limit to our physicality, the consequences of which would be perceivable in cultural semioses? So far, contesting sports prove that this is not so. Beating a record, even by a fraction of a second, is culturally *meaningful*, although it is not in any way spectacular, i.e., a race, in which a present record has been beaten by hundredths of a second. When based on the perceptual abilities of a humans' senses, there is no difference with the previous result, which was worse by several centimetres (as compared to the hundreds for the entire race) that was run in the same time. A competitor who arrives hundredths of a second before his rivals is not distinguished by anything that could be perceived as a special "winner's trait". Nevertheless, the meaning and the pragmatic effect of being a record holder is qualitatively different from finishing in any other place. Scientific certainty, which is here to minimalize the possibility of making a mistake, as well as generally deciding what the competitors' ranking should be, excludes man as a referee in the process of taking decisions. A referee, with his or her imperfect perception, becomes a controller of formal correctness during the course of a competition; however, it is not he who picks the winner, but electronic measuring appliances, the reading of which is sanctioned more by the lack of protest on the part of a referee than by a creative act of will.

Thanks to the media, despite the blatant refereeing errors, performing sports do not need to worry about their decline in popularity; on the contrary, together with an increasing presence and the abilities of new channels of media transmission, e.g., the Internet, there is a growing number of potential fans who do not mind an occasional refereeing mistake. An important reason of taking part (also thanks to live broadcasts) in this type of sporting events is experiencing the impressions and emotions during its course, i.e., creating sign relations, in which emotions and energetic reactions that accompany watching sport are *meaningful*. It is a sufficient reason to preserve the regulations and refereeing techniques applied so far, as they work well in practice, since there is no decrease in the interest in performing sports. A goal is a goal, its scoring is usually perfectly visible from the audience and it is not necessary to measure with a laser beam whether a ball has been stopped by the net when the whole goal post is shaking.

The division into contesting and performing sports is made on the basis of a sport's discipline, but it is not strict since a contesting event can generate interpretations connected with its performing qualities and just the opposite. For instance, if during a given competition a world record is set, and a contestation takes place more than once, undoubtedly the event takes on performing qualities, differentiating it from similar events in which even singular contestations seldom occur.

In the context of physical freedom, an interesting moment would be the moment of reaching the limits of a human body's abilities in contesting sports. If records cease to be set, will prestigious sports stop evoking any interest since the best contestants would only differ in a way unperceivable to the human senses? Will an occasion to watch an extremely prestigious 100 metre run, which takes about 10 seconds, fill up an Olympic stadium if the chance of beating the present records is negligible or even zero? At present, as long as record are beaten, contesting sports cannot be said not to possess a performing quality for fans and, not less importantly, for the media (the fact that being present at the Olympic Games or championship is unrepeatable but formally has no influence on the result achieved). It is something unique to be in the audience when a world record is set. However, if the element of expectation in witnessing the next overcoming of the limits of human physical abilities disappears, will contesting sports keep their meaning in culture?

Conclusion

In the adopted research perspective, sport is a positive valuation of physicality, which is proved by the enormous cultural significance of world records set in contesting sports. The affirmation of physicality does not require a previous necessary axiological superstructure taken from the field of traditionally understood ethics or teleology. It means, among others, that the value of sport in the semiotic context of physical freedom is not subjected to the principle of *fair play* or to any other principle.

Running a certain distance within a certain time, scoring a number of points which have never been scored before, i.e., generally speaking, the setting of a record, in itself does not seem to have a value, which appears only through a proper interpretation in a given society or culture (as well as the global culture). However, if we assume that sport is a form of fighting against the determinism of the world, every shift in the limits of human abilities is automatically valuable, independent of culture and time. In this case, the momentary context of a sporting achievement is of no importance, because the physicality in itself ennobles itself by its own achievement and success, its own creation. It is perfectly apparent in the case of contesting sport, the context of meaning of which is, in my opinion, the metaphysical problem of freedom of a human being. Freedom is such a universal value, that in this respect seems to be independent of time and place.

However, if we assume that the freedom of will in making undetermined choices (initiating action) does not exist, it does not mean negating physical freedom at the same time. The issue analysed in this article is not one of determinants, which prompted the will of a given athlete towards physical activity, or the lack of them, but the problem of what the cultural meaning of overcoming subsequent limits established by sports records has. It would be naive to think that in the future we may expect an inevitable progress of records which in consequence will lead, for instance, to setting the record for the 100 metres run to less than 5 seconds. Thus in this sense, the freedom of body is limited. This type of limit, however, is meaningless, just in the same way as it is meaningless for the freedom of will, in that it cannot make hundreds or thousands of choices per second.

The evaluation of the value and meaning of physical freedom in the context of modern contesting sporting events can be done thanks to the methods based on semiotics, and especially on C.S. Peirce's *semeiotic*. Signs, the object of which is physical freedom (signs that represent the freedom of a body) are sports records, set in conditions controlled by scientific methods. For some sports, called in this article contesting, beating the present record has an overriding value in relation to other advantages of the competition which are basically subordinate to the "record form" of a contestant. A record is translated into a number of meanings and interpretations, among others a commercial one, which, due to the persistence of commercials, may seem overriding, thus reducing sport to a way of earning money. The meaning of records in culture is best seen from a certain temporary distance. We usually remember who the record holder was, giving lesser significance to the precise results that constituted the record at that time – this is *semiotic abrasion*, in which the object of a sign, i.e., a record, becomes substituted by the role of the athlete, representing the success of man in the fight with the determinism that limits our physicality.

Footnotes

1. In order to realise the complexity and the multithreading of the problems of freedom, it is enough to mention that the problem occupied the minds of such thinkers as Plato, Aristotle, stoics, St. Augustine, Descartes, B. Spinoza, I. Kant, G.W.F. Hegel, A. Schopenhauer, F. Nietzsche, J.S. Mill, W. James, E. Fromm, J.P. Sartre as well as many others. In the present article I purposefully limit the research perspective to freedom in the context of determinism – indeterminism.
2. Undoubtedly, one can assume a perspective in which strenuous attempts at breaking records, particularly in sports, can be interpreted as the evidence of the limits of our physical sphere and not of its potential freedom and indeterminism. Similarly, manned flights in space can be evaluated as a proof of our limited physical and technological abilities and not as the "exploration" of space, in the scale of which our "achievements" and the distance covered so far is less significant that thousandths or even billionths of seconds by which subsequent records are beaten.
3. Relying on Peirce's semiotic, or, more precisely, *semeiotic* propositions, it is impossible to quote a single source, where they are concentrated in synthetic and final form. The most known anthology of sources is *Collected Papers…* [2], which however, due to the artificial fragmentation of original works made by the publishers, is not free from faults. Nowadays an increasing popularity is enjoyed by the chronological publication of *Writings…* [3]. Nevertheless, the fastest and approachable introduction to Peirce's semiotic are elucidations of known and valued researchers of the subject, such as H. Buczyńska-Garewicz [4] or J.J. Liszka [5].
4. It is worth noticing, that profound analyses of the phenomenon of sport and sporting competition, e.g. as done in the works of R. Barthes [9], are rooted in the field of semiological tradition. As the author of the present article I do not undertake to judge which methodology is more efficient in the semiotic study of sport.
5. Especially popular among researchers of the phenomenon of sport are the divisions based on J. Huizinga's propositions (the category of *homo ludens*) [16] or their developments and modifications in the spirit of sociology, made by R. Caillois [17], which define sport mainly in the connection with the category of *game*.
6. The term *performative* in the tradition of the philosophy of language functions in the meaning proposed by J.L. Austin, who differentiates *performative utterances* (*performatives*) and *constating utterances* [18]. In the division into performing and contesting sports that I propose, the term *performance* is used in the meaning referring to performing arts, the essence of which is the uniqueness of an artist's performance. Performance is not fully determined by the existence of an act of art in the consciousness of receivers and can proceed in a way artistically unexpected and surprising. Similarly, the performance of a athlete, especially during a rare and prestigious sporting event, can take on a unique character, a constituting complement of which will be the presence of other participants of a sporting event (spectators), who take the role of interpreters of the *existing* situation.

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THE BODY AS A FORM OF ID AND SOCIAL DIFFERENTIATION (IN ANCIENT GREECE)

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ABSTRACT
The aim of the article is the presentation of the philosophical approach towards the human body against a background of broader culture and social context. In ancient Greece, the corporeal nature of man was a category strongly linked with a precisely understood form physical culture, including both philosophy and medicine and what we would call today 'physiotherapy'. In antiquity, rank and a person's social status was assessed not only by the quantity of material goods owned, but also by the superiority of one's body and their fitness level; the physical form. Those who were disabled were disposed of or outcast. The human body was treated as a kind of identification card, which contributed to the development of numerous social divisions. This paradigm was supported both in practice and theory by such outstanding thinkers as: Aristotle, Plato, Socrates, Hippocrates, Pythagoras and Diogenes of Sinope.

Key words: human body, man, philosophy, ancient times

Starting from the first ancient Olympic Games, when immersed in the social reality of that time, the physical body of a citizen, and especially the body of an athlete, was strongly marked (and branded in some cases) by ethical opinion. Expressing this idea more precisely, the body was a kind of transparent, legible and clear social form of identification for the majority of one's fellow citizens. And it remains the same today: the body isn't merely a tool, the material substratum, which – like clothing – is something a person wears. The body is the basis for creating a person's image and the way they are perceived, categorization and assessed. In many cases (often hastily) this kind of categorizing gives rise to diversified social differentiation. Some people want to emphasize their affiliation to certain social groups and even subcultures with their particular physical appearance (e.g. by appearing "fit" or with a muscular build). The best example of this is those who are physically active and those who actively practise sport. Both amateurs and professionals, for instance models and managers (for whom their body is their job as well as a business card) as well as bodybuilders and combat sport fighters. Among them there are also stadium hooligans and football pseudo-fans, who wish to emphasize their strength and efficiency through their physical appearance. It serves as a way of dominating over other weaker opponents. Therefore it is not only athletes who are judged on the basis of their physical appearance.

All over ancient Greece – the "homeland" of the Olympic Games and of European philosophy (being such different domains of human activity, they are curiously adjacent[1]) – there prevailed a similar attitude towards the body and almost identical way of taking care and exercising it. The Hellenic peoples (inhabitants of Athens, Macedonians, Spartans etc.) had similar attitudes towards corporality and physical activity, similar methods of treating physical disability and mental impairments. Youth, strength, efficiency and health were treated as a gift of fate and luck, which could be increased through physical exercise. Old age, limited psychomotor abilities and possible disability was evidence of losing the favour of the of gods, a curse that gave grounds to committing suicide for many people. In the Greek Pantheon, almost all of the Olympic gods[2] were perfectly built and remarkably physically fit: both women (e.g. Athena, the patron of the capital of Greece) and men, with Poseidon and Zeus (presented in iconography as a mighty thrower of fiery javelins) were at the head. These gods, immortalised in ancient sculptures, can still arouse astonishment mixed up with a sense of jealousy. It happens even today that when seeing a well-built person we use expressions such as "divine body" or "sculpted" whether by nature or physical exercise.

Greeks regarded those who didn't exercise, couldn't swim or didn't speak Greek (with its hundreds of dialects) as barbarians. Physical activity, built around a sports mentality, was organized by parents and the state and was practised from early childhood until old age. In addition, it was also always naked (irrespective of age): both during "training" and during the most important sport competitions; whether local or general-Greek (Olympic, Isthmian, Nemean, Pythian). A classicist of sport sociology – Zbigniew Krawczyk – observes, "The competitors' bodies of the Olympic Games entered the reality of the sacred world with a double meaning: instrumental – as a tool of success offered to the gods, and intrinsic – as an object of worship and adoration by the society of the polis" [1, p. 104]. It might also have been the reason why, before exercising, each contestant completed a series of careful ablutions (similar to religious ceremonies). A former Olympian, and today an ethnologist of sport – Wojciech Lipoński – found that, "The most common form of baths in ancient Greece were the *balneum* or *balineum* (Greek for *balaneion*, Latin for *bathwaters* – baths). Balneum were a set of sanitary devices, and at the same time considered having a sporting nature, functioning close to gymnasia, private houses and also as separate complexes of public buildings; it also stood for the style of sanitary and recreational activities that took place there, consisting of baths, massages as well as associated cultural activities. Separate balaneum were built for women and for men" [2, p. 284]. Women were excluded from this definitely male world of physical culture and sport and they participated in their own, although rarely held, competitions – e.g., the Heraean Games.

A good way to illustrate this argument is through the Homeric story of Odysseus who washed up completely naked on a shore as a castaway – without any insignia or other signs of affiliation to any social group. His only social discriminant was his body, the look of which has already suggested something to the observers. It was also a valuable clue and basis for his ethical evaluation. "Ill fashioned, at least, he is not in his thighs and sinewy legs and hands withal, and his stalwart neck and mighty strength: and he lacks not youth, but is crushed by many troubles" – we can read in Homer's Odyssey [3, p. 114]. Appearances can be misleading though. Therefore, the interlocutor, in trying to verify Odysseus, persuades him to take part in a sports contest, which would be the best way to test one's nobility, and therefore provokes him, challenging him to a duel. He insults Odysseus, pointing out the probable ignorance of such noble entertainment as sport rivalry. He compares him to a sea worker who earns their living through hard physical work (which could explain the above average body build and powerful musculature of Odysseus). Only after being provoked does Odysseus hurl with impressive momentum a bronze discus far beyond the finishing line is he identified as being "of noble birth". His physical build does not arouse the slightest doubt anymore and he is complemented on his physical competence. The skills he possesses are an adequate and sufficient proof of his social affiliation. Therefore, they require no further verification: the anonymous and suspicious figure of Odysseus is included into the exclusive circle of aristocrats. Thanks to sport does an act of social incorporation allow Odysseus to become unconditionally accepted as being "one of them".

Having leisure time and the chance of utilising it for practising sport was for Hellenes a defining characteristic of social elite. Spartans (largely men, women to a lesser extent) – devoted almost all of their time to body building, trying to reach a state of complete perfection. Fitness was useful both in the pankration (a kind of "catch wrestling") during the Olympic Games, as well as in war which Spartans most willingly occupied themselves with, treating sport as relevant preparation for this bloody craft. The Spartans, however, didn't possess an advanced form of spiritual culture, which was considered inseparable with physical culture, that other Greeks could boast about. It was not by accident that one of the most outstanding ancient philosophers – Aristocles – gained the pseudonym "Plato" thanks to his gymnastics teacher (who today would be labelled as a "coach" or an "instructor"), as "Plato" meant broad-shouldered.

Władysław Witwicki, a translator and a commentator on the works of this philosopher, who was the founder of the first schools in Western civilization (the "Academy"), on account of its location (on a former sports facility) and predilections of the founder (who himself was the winner of many prestigious competitions) – which could also be considered a prototype of today's University School of Physical Education – wrote: "Plato has already served then in the Athenian army. He started his service as an eighteen-year-old young man (...) he willingly came back from the fields to leave for Athens, in order to talk with friends, to practise sand wrestling and to bathe" [4, p. 11–12]. On the other hand, Andrzej Tyszka notices, that "(...) the image of the great philosopher, in the form of the classical bust, was dug up on the edge of an ancient stadium in Olympia amongst the busts of other winners" [5, p. 160]. Only the winners could place such their sculpture in a stadium (unlike *zanes*, which cheaters had to put up their busts at own expense due to not following ethical principles, now known as "fair-play"). These "monuments of shame" (*zanes*) "(…) were set up as a warning along the wall the terrace leading to the stadium entrance" [6, p. 39].

Greeks wishing to spend their leisure time effectively had a lot of sports centres to choose from, where they could practise athletics and weightlifting from dawn till dusk, suited to their taste and liking. Werner Jaeger highlights this fact, that: "At the gymnasium, an Athenian of those times felt more at home than in his own (…) where he came to sleep and to refresh himself. (…) everyone who had something to say or wanted to learn something of more general meaning (…) went with it to friends and acquaintances at the gymnasium" [7, p. 585]. Sports centres functioned as our erstwhile "community centres", and of today's fitness clubs, to which – during one's spare time – one comes not only to shape the body with diverse exercises, but also to establish useful contacts, to relax, to rest among interesting people with similar preferences and (probably) of similar financial and social status.

At ancient sports centres (private and national) it was also possible to brush up on one's general and detailed knowledge of the world. "The environment, in which Socrates socialized, was not (...) some (...) lecture hall. The appropriate background for his speeches was the busy life of an Athenian sports stadium (gymnasium), where his presence soon became not only a daily but a necessary marvel to behold, both as a gymnast or a doctor" [7, p. 585].

Admittedly Socrates left no writings for us, but he often and willingly danced, thinking it of an exercise well disposed towards preserving good physical fitness and health. A painter from the turn of the 18th and the 19th century – Jacques-Louis David – in the picture "Death of the Socrates" presented this sage at the last moments of his life in such a way that the musculature of his torso, hands and legs were not only clearly visible but even emphasized. What is more, the eminent master Socrates was then about 70 years old, but (in the painting) he was deprived of the physical deficiencies so characteristic of the elderly. After Socrates' death, as a token of mourning, all the gymnasiums and palaestras were closed, which for us, in today's time, may perhaps be seen as something unprecedented. Today we find other ways of honouring those who rendered a great service to physical culture and sport, an example being the deputy-mayor of Poznań who died in 2009, for whom football fans said an enthusiastic farewell at the municipal stadium [8, 9].

In the classical "golden age" of Greek culture (between the 5th and 4th century BC), the ideal model of an excellent citizen became widespread, the idea of *kalokagathos*. "The word *kalokagathos* consisted of two adjectives. The first of them, *kalos*, meant an extremely fit man, an athletic participant in Olympic competition, beautifully and harmoniously built. The other word *kagathos* (good) expressed the ideal of a perfect man both morally and intellectually" [10, p. 63]. At first, this model was implemented only by aristocrats, it then gradually, however, became democratized (democracy being yet another important Greek "invention" – besides the Olympics and philosophy) and becoming more common in a larger number of people in the lower social classes and groups. Plato, seeking perfection in man and a utopian society built on such people, was convinced that if "(…) somebody does a lot of gymnastics (...) and doesn't touch music and philosophy (…) isn't he gaining confidence (…) isn't he becoming ever braver? [If] he doesn't try to learn and does not redeem himself with thinking or any other cultural interest [he] becomes an enemy of intellectual and spiritual culture; someone who isn't able to prove anything effectively in a discussion and acts in a barbaric manner as a wild animal" [11, p. 180].

A thoroughly fit body, but also intellectually well educated, was the sign of a man having high social status in Plato's days. In order to practise sport it is necessary to have the time and adequate means. The social system dominating in ancient Greece supported such an approach: slaves, women and poorer people of low social status who could not afford servants did all the hard work. The musculature of the aristocrat differed significantly from the one of a slave or a craftsman. Similarly, in today's society, a bodybuilder differs in appearance, we could say, from the manual labourer or farmer (although all of them perform equally hard physical work). Plato's disciple, coming from an old family of doctors – Aristotle (the founder of yet another school of philosophy, the "Lyceum") – with protocol precision described both the natural as well as the social world of his time, reminds us: "Cretans (…) granted their slaves all the same rights as them, but forbade them the access to gymnasiums and possessing weapons" [12, p. 51]. The special kind of military-sports competence, directly tied with improving the body and increasing its potential, was reserved exclusively for the elite: wealthy and free citizens.

The free Greek practised all sports disciplines and in all sorts of competitions, unlike us today, who only perform individual activities, selected on account of individual preferences or current needs (losing excess weight, getting in shape before the holidays). In the hot Mediterranean climate, marked by high temperatures and humidity – conditions conducive to naturally exposing the body in public (in particular, being naked when practicing sport) – there was no effective way to hide the body from astute, critical observers; the quality of the body and its appearance, and in particular any lackings, physical flaws and any other significant departures from the norm. What today's readers can readily see in the preserved writings of ancient thinkers (of dramatists, philosophers, historians and poets) is a careful description of a speaker's physical attributes or of any person with a precision usually ascribed to women. If we were to describe today some distinguished member of the public, such as an important academic (e.g. a university professor), we would concentrate on their university degrees and academic titles as well as research achievements. We would be far less interested in their appearance, instead we would describe his or her spiritual depth, the substantive value of their works and the like. When we characterize Leszek Kołakowski, who died in 2009, an outstanding Polish philosopher and academic professor who was greatly appreciated abroad, we would only bring attention that he had already been using a walking stick during his studies, that he was tall and remarkably slim – and we end it there. Yet here is a description of the ancient philosopher Menedemosa, provided by Diogenes Laertius: "(…) till his advanced years he kept good physical fitness. He had a strong body, firm and tanned, from spending time in the open air, like an athlete. He was of average height, as portrayed in his statuette, found in an old stadium in Erétria; the sculptor, certainly on purpose, presented him not in robes, but almost naked, almost entirely showing his whole body" [13, p. 154]. And by no means was such a character description an isolated case in ancient times.

Those Greek citizens who wanted to hold important state positions and to climb the ladder of social hierarchy naturally tried as hard as possible to camouflage the deficiencies of their imperfect body; their effort, however, was in vain. Even during the zenith of ancient Athens (as a cultural centre), the majority of men knew each other personally, by sight or at least having heard of one another from time to time. Quite naturally they met in such public places as gymnasia, baths, the town market (performing polyfunctional roles), the stadium or the theatre. Social approval for the widespread use of eugenics (of which Plato was also a supporter) effectively eliminated the more disabled humans from Greek society. The Spartans in this respect were exceptionally rigorous, entirely and ruthlessly ridding frail and imperfect children right after their birth. Few exceptions confirm to this rule. Even in a scene from the film "300" conveys this notion very well. A horribly deformed Spartan, miraculously kept alive thanks to the boundless love of his parents, wants to help his countrymen, but even in a time of great peril this is made impossible to him. The commander of the army, Leonidas, as a first impulse, tries to immediately kill the cripple, piercing him with a spear.

If a disabled man (to some extent) was to be (somewhat) accepted, he had to be in possession of some extraordinary abilities (in art or craft). Just as blind Homer, whose canonical texts, the "Illiad" and "Odyssey", were passed on orally, on which entire generations of Greeks based their ethical and utilitarian values. The gift of making speeches secured the political career of a few outstanding figures. A famous Athenian politician can serve as an example here – Pericles. Plutarch from Chaeronea describes him: "(…) he was a child of normal physical build, apart from the fact, that he had an elongated head that was disproportionately large. That is why in almost all of the images of Pericles is he shown a helmet on his head. Apparently artists didn't want to make him an object of ridicule" [14, p. 59]. The equally famous politician and orator – one of the most outstanding speakers of ancient Greece – Demostenes was described in a similar way. He could be regarded as the "father of speech therapy". Due to a serious speech defect from birth, he would walk to the beach and put stones in his mouth in order to correct his speaking skills. With time, as a result of these spontaneous rehabilitation treatments, his linguistic abilities achieved perfection. The last example is a "different Olympic champion", described by Pausanias: "Pyrrho of Elis (…) achieved one victory in the pentathlon in Olympia, second in Nemea (…). In childhood he suffered muscular dystrophy as a result of rheumatism which made him take up the pentathlon in order to become a man healthy and immune to illness. These exercises were supposed to give him a series of dazzling victories in the future" [15, p. 140].

The careers of Paralympic competitors arise in a similar way. They usually begin from an illness or disability, continue with treatment and rehabilitation and then smoothly pass into training, and then, after acquiring essential motor competence, they continue on to competition; often at a world-class level. In this respect, an unprecedented case was the challenge presented to contemporary sport by the legless runner from the RSA, Oscar Pistorius, who after winning numerous gold medals and breaking the world records in the 100, 200, 400 m run, demanded from the International Association of Athletics Federation, the IAAF, and International Olympic Committee", the IOC, the right to start with fully abled competitors in the Olympic Games in Beijing in 2008. And after many up and downs he (legally) became entitled to do so, although he didn't qualify to go to the games [16, 17]. Pistorius started at the Paralympic Games and once again won all the most important runs.

In ancient Greece, a disabled body led to one becoming a social outcast in most cases. The examples that were given above were the few exceptions to this rule. For example, Aleksander Krawczuk gives the following story: "One of the slaves, a boy named Tallus, suffered from attacks three or four times a day. He fell to the ground with froth forming around his mouth, he banged his head on the floor in all directions, he looked horrible. (…) Not for the world would any servant eat with him from the same bowl, nobody would drink from the same cup on which he first put to his lips. And as soon as he entered the room, everyone spat in his direction in order to turn his bad spirit away" [18, p. 47]. There is a similar parable among contemporary people, fearing contact with people afflicted with AIDS or HIV so as not to become infected through touch. It is also the case of the present-day disabled. Many people are convinced (and often the disabled as well) that their disability was a punishment for some alleged sin or offence. An even clearer and even more drastic example of discriminating against the disabled is given by Plutarch of Chaeronea. The one and only Alexander of Macedon, the hegemonic leader of the world at that time, was a participant in this event which occurred in his youth when he was Aristotle's disciple. "And once after having a bath, a young servant who was very disabled and of funny appearance, but who could sing beautifully, stood too close to Alexander." Later, the combustible properties of petroleum were tested on him, which the Greeks encountered for the first time in Babylonia [14, p. 182]. Out of curiosity, some experimenters set fire to the cripple! Although he was quickly extinguished, the boy was badly burnt and suffered for the rest of his life.

The social marginalisation of those who diverged from the universally accepted canon of physicality was not only accepted by enlightened and educated figures, but even those who were responsible for educating others. An example can be seen in the meeting of two eminent thinkers, one of whom was paralysed. Upon meeting each other, the healthy colleague refused to shake hands with the cripple, who was none other than Speusippus from Athens, the successor and later director of Plato's "Academy". Or, when "(...) one day a man met Diogenes who was being carried on a little cart to the Academy and greeted him, the man replied: 'but I cannot greet you, you who agrees to live in such a state'. Finally, being a man of advanced age and depressed, he committed suicide" [13, p. 216]. Diogenes of Sinope, as a cynic living in a barrel in the centre of Athens, ruthlessly and brutally expressed opinions that were probably shared by many citizens. At the same time he became the executor and instrument of social pressure. When the duty of educating children that were put into his care fell on him, he carried it in such a way, "(...) that apart from other abilities the children learnt to ride a horse, to shoot arrows from a bow and a sling as well as to throw the javelin. And in the palaestra he didn't allow the director of the school to bring the boys up as athletes, but only to use exercises that would give them a healthy complexion and which exercised the body" [13, p. 326]. As a philosopher he criticised the contemporary system of physical education, however, in practice, he carried it out. "He also said that people are going in competition with each other when it comes to performance (...) such as with leg exercises, yet no one competes in order to become morally perfect" [13, p. 325].

Ancient Greek culture was tied to physical culture and in many respects was identical to it (for instance, in the form of agonistics, where the Greek word *agon* meant competition). Plato willingly gave his lectures outdoors, with intervals for resting and physical exercises. This mobility was in harmony with the style of his pioneering works, which were philosophical dialogues (like the protocols of a "verbal duel" or of "mental wrestling"). The unhealthy Epicurus of Samos had a school in Athens in a garden (hence the customary name given, "The Philosopher from the Garden"). Aristotle, on account of his "leisurely pace" when giving lectures, was called "Peripatetikos" ("The strolling", from the Greek word *perípatos* – to stroll, walk), which even to today he is still sometimes called "The Great Peripatetic". Care of the body and good physical fitness was an ethical imperative carefully obeyed in some philosophical schools (e.g., the Pythagoreans, i.e., the pupils of the schools of Epicurus of Samos). It also laid the idea of kinesiotherapy (Greek *kinesis* – movement, Greek *therapeo* – to cure, lit. "treating with movement"), which in its archaic beginnings enjoyed great success in ancient Greece. Its supporters were the greatest minds of those times, with the philosopher and sports champion Plato as well as the "father" of European medicine, Hippocrates, at the head. Plato was 33 years younger than Hippocrates, who, when he arrived in Athens in search of knowledge, first directed his steps to the philosophical schools. Aristotle and Plato named Hippocrates "The Great", although he was of a rather inconspicuous, frail physique. Hippocrates' teacher, Herodicus, "(...) as one of the first amongst Greek doctors recommended physical exercises for different diseases. Exercises that were intensive enough to have injured his patients. Hippocrates was opposed to these practices (460–337 BC) and was a great supporter of taking walks, marches and runs, fulfilling both preventive, as well as healing functions" [19, p. 25].

It would be perfect, if these two spheres of typical human activity – ethics and sport – went hand in hand with each other. For this, however, physical culture requires the support of philosophy, which includes ethics. Aristotle, both the philosopher and the doctor, found the following solutions: "(...) gymnastics will establish, what type of exercises are for the body beneficial and the best – obviously, what is natural is the most beneficial, therefore the best conditioned body requires the best form of training – it will also establish (as this is what gymnastics are) what type of exercise for the largest number of people are the best (...) Even if somebody doesn't want to achieve the degree of agility and ability which is featured in competition, it nevertheless remains the task of the teacher to give them the training and physical endurance to at least introduce one to this art" [12, p. 147]. On the other hand, in the "Nicomachean Ethics", Aristotle expressed the following opinion: "But not only are spiritual defects dependent on will, but also the physical errors of some people, whom we also criticise; but nobody criticises the ones, who are naturally ugly, however, we criticise those who are ugly through the lack of physical exercises and their neglect. (...) It is similar with illness and disability; as no one could abuse one who is blind from birth or who suffered after an illness; rather we would feel sorry over him. However, everyone would reprimand the man who lost his eyesight due to drunkenness or other excesses. So it is that those physical ailments that are dependent on us can in fact be reprimanded, while the ones which don't depend on us, cannot be" [20, pp. 132–133].

The holistic development of a person, according to Aristotle and Plato, cannot go beyond the borders of common sense, one should search for the "golden balance". Physical exercise is supposed to be the means to a goal, which is the harmonious development of a human being and all of his abilities; both intellectual and moral (spiritual), as well as physical. Aristotle held the view that the beauty of a person can be built on the material basis of his corporality. Aristotle regarded the pentathlete as the upholding example of a beautiful athlete. This is what he wrote about pentathletes: "The beauty of a young man is connected with having a body capable of bearing great hardships and the trails of strength, and at the same time gives pleasure to those who look at them. Therefore, pentathletes are the most beautiful, as nature equipped them with both power and speed" [21, pp. 85–86]. This last sentence may be the perfect presentation of the perfect man, something Friedrich Nietzsche dreamt of when he wrote about his "superman". All, of course, under the condition that while doing physical exercise he would also indulge in a little philosophy.

Footnotes

1. The first Olympic Games date to 776 BC, whereas philosophy as a science appeared only about 100 years later in the same region of the world, which can be considered as a puzzling social phenomenon.
2. Only the delicate Hephaestus was a "god-cripple", being club-footed, but he distinguished himself with a number of useful practical skills, that others, according to Greek mythology, willingly took advantage of. While on the subject of mythology, it is worthwhile to mention the Amazons, a tribe of brave women deprived of their right breast (Greek *amadzones* – without a breast), as it interfered in effectively firing the bow and arrow. Today, a woman after a mastectomy (a resection of the breast) is sometimes described as an "Amazon".

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   – skrócony tytuł artykułu w języku angielskim (do 40 znaków ze spacjami), który zostanie umieszczony w żywej paginie;

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5. The second page should contain:
   - The title of the article
   - An abstract, written in English, of approximately 250 words divided into the following sections: Purpose, Methods, Results, Conclusions
   - Three to six keywords to be used as MeSH descriptors (terms)
6. The third page should contain:
   - The title of the article
   - The main text
7. The main body of text in empirical research articles should be divided into the following sections:

Introduction

The introduction prefaces the reader on the article's subject, describes its purpose, states a hypothesis, and mentions any existing research (literature review)

Material and methods

This section is to clearly describe the research material (if human subjects took part in the experiment, include their number, age, gender and other necessary information), discuss the conditions, time and methods of the research as well identifying any equipment used (providing the manufacturer's name and address). Measurements and procedures need to be provided in sufficient detail in order to allow for their reproducibility. If a method is being used for the first time, it needs to be described in detail to show its validity and reliability (reproducibility). If modifying existing methods, describe what was changed as well as justify the need for the modifications. All experiments using human subjects must obtain the approval of an appropriate ethnical committee by the author in any undertaken research (the manuscript must include a copy of the approval document). Statistical methods should be described in such a way that they can be easily determined if they are correct. Authors of comparative research articles should also include their methods for finding materials, selection methods, etc.

Results

The results should be presented both logically and consistently, as well as be closely tied with the data found in tables and figures.

Discussion

Here the author should create a discussion of the obtained results, referring to the results found in other literature (besides those mentioned in the introduction), as well as emphasizing new and important aspects of their work.

Conclusion

In presenting any conclusions, it is important to remem-

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- nazwę uczelni, nazwę miejscowości, nazwę kraju, np. Akademia Wychowania Fizycznego, Wrocław, Polska;
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5. Następna strona powinna zawierać:
   - tytuł artykułu;
   - streszczenie w języku angielskim (około 250 wyrazów) składające się z następujących części: Purpose, Methods, Results, Conclusion;
   - słowa kluczowe w języku angielskim (3–6) – ze słownika i w stylu MeSH.
6. Trzecia strona powinna zawierać:
   - tytuł artykułu;
   - tekst główny.
7. Tekst główny pracy empirycznej należy podzielić na następujące części:

Wstęp

We wstępie należy wprowadzić czytelnika w tematykę artykułu, opisać cel pracy oraz podać hipotezy, stan badań (przegląd literatury).

Materiał i metody

W tej części należy dokładnie przedstawić materiał badawczy (jeśli w eksperymencie biorą udział ludzie, należy podać ich liczbę, wiek, płeć oraz inne charakterystyczne cechy), omówić warunki, czas i metody prowadzenia badań oraz opisać wykorzystaną aparaturę (z podaniem nazwy wytwórni i jej adresu). Sposób wykonywania pomiarów musi być przedstawiony na tyle dokładnie, aby inne osoby mogły je powtórzyć. Jeżeli metoda jest zastosowana pierwszy raz, należy ją opisać szczególnie precyzyjnie, przedstawiając jej trafność i rzetelność (powtarzalność). Modyfikując uznane już metody, trzeba omówić, na czym polegają zmiany, oraz uzasadnić konieczność ich wprowadzenia. Gdy w eksperymencie biorą udział ludzie, konieczne jest uzyskanie zgody komisji etycznej na wykorzystanie w nim zaproponowanych przez autora metod (do maszynopisu należy dołączyć kopię odpowiedniego dokumentu). Metody statystyczne powinny być tak opisane, aby można było bez problemu stwierdzić, czy są one poprawne. Autor pracy przeglądowej powinien również podać metody poszukiwania materiałów, metody selekcji itp.

Wyniki

Przedstawienie wyników powinno być logiczne i spójne oraz ściśle powiązane z danymi zamieszczonymi w tabelach i na rycinach.

Dyskusja

W tym punkcie, stanowiącym omówienie wyników, autor powinien odnieść uzyskane wyniki do danych z literatury (innych niż omówione we wstępie), podkreślając nowe i znaczące aspekty swojej pracy.

Wnioski

Przedstawiając wnioski, należy pamiętać o celu pracy ber the original purpose of the research and the stated hypotheses, and avoid any vague statements or those not based on the results of their research. If new hypotheses are put forward, they must be clearly stated.

Acknowledgements

The author may mention any people or institutions that helped the author in preparing the manuscript, or that provided support through financial or technical means.

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> Tchórzewski D., Jaworski J., Bujas P., Influence of long-lasting balancing on unstable surface on changes in balance. *Hum Mov*, 2010, 11 (2), 144–152, doi: 10.2478/v10038-010-0022-2.

If there are six or less authors, all the names should be mentioned; if there are seven or more, give the first six and then use the abbreviation "et al."

If the title of the article is in a language other than English, the author should translate the title into English, and then in square brackets indicate the original language; the journal title should be left in its native name, for example:

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> Osiński W., Anthropomotoric [in Polish]. AWF, Poznań 2001.

> Heinemann K. (ed.), Sport clubs in various European countries. Karl Hofmann, Schorndorf 1999.

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> McKirnan M.D., Froelicher V.F., General principles of exercise testing. In: Skinner J.S. (ed.), Exercise testing and exercise prescription for special cases. Lea & Febiger, Philadelphia 1993, 3–28.

oraz postawionych hipotezach, a także unikać stwierdzeń ogólnikowych i niepopartych wynikami własnych badań. Stawiając nowe hipotezy, trzeba to wyraźnie zaznaczyć.

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> Tchórzewski D., Jaworski J., Bujas P., Influence of long-lasting balancing on unstable surface on changes in balance. *Hum Mov*, 2010, 11 (2), 144–152, doi: 10.2478/v10038-010-0022-2.

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> Jaskólska A., Bogucka M., Świstak R., Jaskólski A., Mechanisms, symptoms and after-effects of delayed muscle soreness (DOMS) [in Polish]. *Med Sport*, 2002, 4, 189–201.

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Donsmark M., Langfort J., Ploug T., Holm C., Enevoldsen L.H., Stallknech B. et al., Hormone-sensitive lipase (HSL) expression and regulation by epinephrine and exercise in skeletal muscle. *Eur J Sport Sci*, 2 (6), 2002. Available from: URL: http://www.humankinetics.com/ejss/bissues.cfm/, doi: 10.1080/ 17461391.2002.10142575.

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